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Regional harmonization procedure for prioritization of recycled material specifications

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REGIONAL HARMONIZATION PROCEDURE FOR PRIORITIZATION OF RECYCLED MATERIAL SPECIFICATIONS

BY

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ABSTRACT

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Widely varying recycled material requirements across state lines has been perceived as a significant barrier to greater use of recycled materials in highway construction by state contractors and industry. The goal of this thesis is to create a procedure to compile, compare, contrast and finally synthesize documents that support a priority list of recycled materials and applications for which material specifications can be harmonized among regional states in the US.

This work compiled background research on selected materials and related regulations into standardized templates. The information analyzed was communicated with EPA, FHWA, and state representatives to approve a breakdown priority list and discussed through a working meeting to make an action plan toward regional harmonization. A life-cycle assessment was conducted in a representative state for the easiest recycled material to harmonize to determine the environmental benefits of use. A prioritization system was created to choose the first material/application specification to harmonize.

LIST OF ABBREVIATION

AASHTO – American Association of State Highway Transportation Officials

ANSI – American National Standard Institute

ASTM – American Society for Testing Materials

BFS – Blast Furnace Slag

BUD – Beneficial Use Determination

CCB – Coal Combustion Byproducts

C&D – Construction and Demolition

CEN – European Committee for Standardization

CENELEC – European Committee for Electrotechnical Standardization

CFA – Coal Fly Ash

CO – Carbon Monoxide

CO_2 – Carbon Dioxide

DC – District of Columbia

DEP – Department of Environmental Protection

DEQ – Department of Environmental Quality

DOT – Department of Transportation

EC – European Community

EPA – Environmental Protection Agency

ETSI – European Telecommunications Standards Institute

EU – European Union

FHWA – Federal Highway Association

HMA – Hot mix Asphalt

HTP – Human Toxicity Potential

GGBFS – Ground Granulated Blast Furnace Slag

GHP – Green Highways Partnership

GWP – Global Warming Potential

ISO – Organization for Standardization

LOI – Loss of Ignition

Mg - Mercury

NO_x – Nitrogen Oxides

Pb - Lead

PM_{10} – Particulate Matter

RAS – Reclaimed Asphalt Shingles

RCRA – Resource Conservation and Recovery Act

RMRC – Recycled Materials Resource Center

SCM – Supplementary Cementitious Material

SFS – Spent Foundry Sand

SO_2 – Sulfur Dioxide

TAG – Technical Advisory Group

TCLP – Toxicity Characteristic Leaching Procedure

TDA – Tire-Derived Aggregate

US – United States

CHAPTER 1.0 – INTRODUCTION

BACKGROUND TO THESIS OBJECTIVE

1.1 Standardization Overview

Standards are an accepted set of criteria met within the market for items such as transportation material characteristics, performance, quality control practices during use, and safe disposal. National quality control standards are guided by the International Standards Organization (ISO) [Reilly 1995], a non-government body founded in 1947, requiring certain standards or quality system audits by a third party certification.

Environmental product standards determine maximum emissions permitted within a specific use, including ambient or process standards. Ambient standards regulate pollutants and enforce quality control; process standards are government environmental regulations for production methods and practices, including performance and design standards. Both ambient and process standards vary by local conditions and environmental preferences between countries, but both contain trans-bordered and global environmental concerns [Stevens 1993]. As these standards have evolved over time in the US and internationally, the focus on the important factors to consider and need for regulation has changed.

History

Of the five core members of the United Engineering Society, the American Society for Testing Materials (ASTM) was established to develop and approve standards, focusing on the safety of the public [astm.org]. As industries evolved, new standards aimed to make products more efficient, cost-effective and safer while still addressing their marketability. ASTM works with technical experts that address users, producers, government and research potentials in over 120 countries [astm.org]. It is one of the largest voluntary standards development organizations in the world, and is known for their technical knowledge.

In 1914, the American Association of State Highway and Transportation Officials (AASHTO) were established [AASHTO 2010] to promote efficient roadway design and construction, and to educate the public and important decision-makers about the significance of selecting transportation materials. It was the first organization to develop national material specifications, and continues to do so, providing over 125 voluntary technical standards for all steps of a product's life, including planning, design, material selection, construction, materials, maintenance and disposal [AASHTO 2010]. It facilitates communication between state's department of transportation (DOT), Federal Highway Association (FHWA) and the government, offers funding for research, helps implement quality control programs, and recommends efficient and cost-saving testing methods for use through the National Transportation Product Evaluation Program (NTPEP) [AASHTO 2010].

In the 1960's, environmental concerns over pollution arose with Rachel Carson's 1962 *Silent Spring* [Lewis 1985], detailing the harmful effects of pesticides; this attracted the attention of public environmental advocates. In response to the pressures for environmental consideration, President Nixon passed the National Environmental Policy Act (NEPA) of 1969, creating the Council of Environmental Quality (CEQ) to advise the president on environmental issues; the purpose was to address environmental problems and find ways to eliminate them. In Nixon's 1970 State of the Union Address [Lewis 1985], he focused on the need to create an independent agency that could enforce environmental protection standards and address environmental concerns, bringing the birth of the Clean Air Act and the Environmental Protection Agency (EPA) in December of 1970.

The International Society for the Environmental and Technical Implications of Construction with Alternative Materials (ISCOWA) [Goumans et al 2003] was created with researchers, industry representatives and policymakers, all volunteers, organized to focus on industrial by-product construction, sharing perspectives on technology, experiences, and new applications. The organization meets every three years at the WASCON conference, dividing into three teams: environmental impact assessment, technical aspects, and policy and legislation. Understanding the history of standardization is important to understand where it is now going, moving from a plain form of regulating materials to bringing policy making together with research to help educate the various states to better use of recycled materials.

Current US Standardization Practice

The current AASHTO specification development process [Justus et al 2003] is illustrated in Figure 1, beginning with a technical advisory group (TAG), comprised of representatives from state DOTs and environmental departments, selecting the materials to investigate. States with the most experience with a given product are viewed as "expert" states [Justus et al 2003] and are used as a foundation for the products standardization; they prepare a list of the potential applications for each material

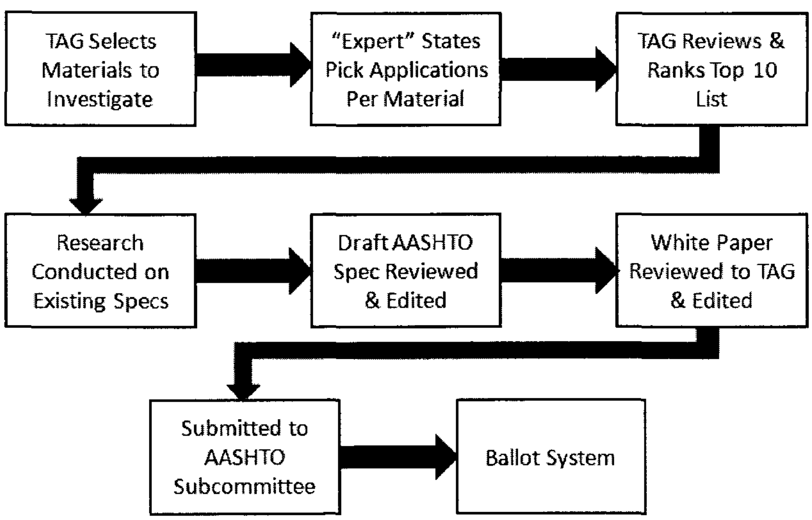


Figure 1 Current AASHTO Standardization Procedure

investigated that the TAG can then review. Once the TAG chooses a ranked list of the top ten materials and applications, the existing specifications are compared and evaluated. A phone survey may be used to ask the states advantages and disadvantages of each material's use in a given application including its performance, its constructability, and the effectiveness of the existing specification. In cases where recycled material specifications are being adopted, the Recycled Materials Resource Center (RMRC) will take charge in the research of the material and the drafting of the specification in AASHTO format and is discussed and edited by technical groups with specialized expertise until the reviewing process is complete.

A White Paper is prepared, including background research, surveys, and any explanations of why each test is required within the specification; the TAG reviews this and circulates it within the members for comments. Once the white paper and specification has been edited, it is submitted to the AASHTO Subcommittee and decided upon through a ballot system.

1.2 Material Standardization Harmonization Overview

Historically, the first attempts at specification harmonization started with combining international methods for developing and implementing standards; four methods include pre-market harmonization, mutual recognition, equivalency and reference standards [Stevens 1993]. Pre-market harmonization organizes common procedures and products for review and approval to enter the market. This method develops guidelines for testing and uses risk assessment to evaluate the harmonized testing procedures. Mutual recognition accepts other state's or jurisdictional boundaries standards, allowing a free flow of goods across borders; an example of this is the food trade within the European Economic Community. This method of harmonization narrows the focus to a set of standards easiest to remove obstacles, but is less successful between countries that vary by environmental preference. The equivalency method recognizes that two different standards may have the same overall effect but differ in conditions and environmental factors, allowing the regulation to be quantitatively different; this method cannot guarantee standards will be able to equally protect health and safety across borders. Reference standards is the most comprehensive approach for harmonization, setting a base standard, and allowing countries to adopt more stringent regulations using scientific reasoning and risk assessment techniques.

For this thesis, the focus was more on product standard harmonization rather than working with ambient standards since product standards are more readily available to harmonize compared to the more variable environmental regulations. Though, working with environmental ambient and process standards together helps to neutralize the differences in inter-country environmental regulations [Steven 1993]. The decision-making process for choosing materials and applications to harmonize can then be influenced by economic instruments and life-cycle management approaches [Stevens 1993]. Economic instruments present fees or permits as financial offsets of the pollutants entering the environment and the charges for public treatment of effluents and wastes. This would be a helpful method to entice the participant toward harmonization. Life-cycle management takes into account the environmental costs with production of products and compares the costs and benefits of using any product. Once a priority list of material and applications were chosen for harmonization based on process standard similarities, an environmental life-cycle assessment could guide the decision-making process further by considering environmental benefits.

History of European Harmonization

In the past, many of the national standards came from a centralized system with standard-setting organizations within the EU; though, with nine different language barriers and as many as 19 sets of varying standards to sell products across Europe, there was a need to reorganize the process [Reilly 1995].

Approved by the Council of the EU in July of 1984 [European Council 1985], the "New Approach" presented a technical harmonization method to resolve technical barriers to trade. It divided the responsibility between EC legislators and European organizations that draft standards.

It was implemented to focus on priority product categories in order to decrease the time and effort on harmonization, including construction materials [Reilly 1995]. It ensured that industrial products were freely marketed and could be used in environmentally safe applications all around Europe, aiming to facilitate harmonization of legislation by the EC and industrial development [European Council 1985].

The EC harmonized product standards, working with international standard-setting organizations to compile and implement a new set of harmonized specifications. The European Committee for Standardization (CEN) divided into a technical standardization and certification segment and a supervision segment [Reilly 1995]. The technical segment conducted expert research, made recommendations and proposed draft standards. The supervision segment, made of a general assembly (such as delegates from each EU nation and representatives from national standard organization), approved proposed standards to be harmonized.

The CEN conducted a voting process, lasting approximately 8 months [Reilly 1995], where each member state received a number of votes proportional to its relative size in the European market. In order for a standard to be considered for harmonization, no more than twenty-two "No" votes or three countries voting "No" was allowed [Reilly 1995]. Member states required approval from the EC to consider any new standards, though it was the responsibility of the individual states to ensure safety with the specification [European Council 1985].

The "New Approach" harmonized standards in areas that mutually agreed on regulations, creating requirements for each product which all members had to meet to make that product suitable for sale. If a standard was viewed as impractical or too difficult to harmonize in certain member states, a document was created outlining the individual requirements for each of those member states [Reilly 1995]. The "New Approach" followed the reference standards method of harmonization; it entrusted competent organizations to define technical characteristics required and enforced continuous checks with the supplier that each product meets the regulations. The priority standards harmonized were analyzed by risk, performance, feasibility and ease of agreement. Though the new approach was not mandatory, it was highly enforced to implement harmonization.

The harmonized standards eliminated trade barriers and prevented the ban on external market products on the basis that they did not conform to the local regulations [Reilly 1995]. It reduced non-tariff barriers from testing and certifying products, as well as standards that would otherwise be costly for producers to meet all the varying requirements for different countries. This allowed the producers to distribute products Europe-wide, improving competitiveness in the EC and external markets.

In response to the European standardization harmonization in the 1980's, the global ISO/IEC Joint Technical Committee on Information Technology was established as the world's largest known standardization committee. Standards became a key component to competitiveness in the marketplace, impacting product development, quality control and conformity assessment between the private and public sectors [ansi.org].

Challenges to European Harmonization

The 2001 Landfill Directive reduced the amount of materials being disposed of in Europe landfills but offered no incentive that would benefit the reuse of waste [European Council 1999]. The Directive led to the CEN's quality specifications but communication was still lacking between the environmental committees and the product performance criteria, leaving national governments responsible for determining the next standards to implement [Goumans et al 2003]. This thesis discussed methods to obtain the sets of standards for harmonization, bringing together industry, state representatives and policy makers.

1.3 Focus on Recycled Industrial Materials

Our National Highways System has over 160,000 miles of roadway, built with asphalt, concrete, steel, aggregate, and other materials; the interstate highway construction began in 1956 [Slater 1996]. Due to roads typical longevity of 15 to 20 years, many of these roadways are left in need of significant rehabilitation or replacement [Lukanen 2003].

Over 4.5 billion tons of waste is generated in the United States annually [Lerner 2003], much of which could be used as an aggregate in highway applications. Europe and Japan, for example, use recycled materials as common practice due to a lack of landfill space and limited aggregate availability. Wastes from pavement manufacturing, such as recycled asphalt pavement (RAP) and recycled concrete pavement (RCP), are wastes of the highest priority currently due to their availability and recyclability on site. While higher priority materials may be efficiently re-used, a number of other waste materials are used less often due to concerns of limited experience of the long-term performance. Therefore, these materials should be analyzed for their environmental behavior, economic benefit and physical performance.

1991 Intermodal Surface Transportation Efficiency Act (ISTEA)

ISTEA [Mineta 1991] was originally passed to evaluate the technical, environmental, and economical aspects of construction materials used in pavements. The act emphasized a need for maintenance and expansion of the national transportation system in an economically and environmentally efficient manner. Funding was provided from 1992-1997 to develop this system and started a process of addressing environmental effects of recycled materials. As a result of the act, FHWA and the Transportation Research Board (TRB) implemented and developed the Recycled Materials Resource Center (RMRC) based at the University of New Hampshire [Chesner et al 2003] to research a wider range of materials. The center develops and maintains guidelines to share with state transportation departments, FHWA, US EPA, the construction industry and other agencies. Recycled materials are tested and analyzed for long-term performance and environmentally sound applications within the transportation infrastructure, helping to reduce barriers limiting its use.

FHWA Recycled Materials Policy

In February of 2002, the FHWA published a memo on the Recycled Materials Policy, illustrating the need to promote the use and reuse of recycled materials [Mineta 2002]. It informed the public that with careful engineering and construction, recycling materials may save costs, time and virgin components in highway applications. Evidence is found in a number of field studies, research and testing, and performance analysis within experimental projects [c.f. Apul et al 2009, Eklund and Roth 2003, NCHRP 1994].

The policy says projects utilizing recycled materials will get first consideration when starting a new project and will be assessed for economic benefits, as well as engineering and environmental suitability. The policy partnered FHWA with the US EPA, RMRC, AASHTO's Subcommittee on Materials, state highway agencies, solid waste management regulators and industry.

Green Highways Partnership

The Green Highways Partnership (GHP), formed in 2005, integrates transportation and environmental concerns to "improve natural, built, social, and environmental conditions, while sustaining the life-cycle functional requirements of transportation infrastructure" [Jeffers 2006]. Recycle and Reuse, one of three concepts the GHP focuses on, is the basis for this paper, encouraging efficient, cost-effective and environmentally sound use of recycled materials in highway applications.

At the Green Highways Partnership Recycle/Reuse Workshop in August of 2007 [Transtec Group 2007], PennDOT's Ken Thorton presented on the topic of Pennsylvania's use of recycled industrial by-products. He noted a lack of experience with recycled materials, uncertainty of cost competitiveness and a lack of standardized specifications to guide the state in properly using the material. General Permit and Beneficial Use Chief, Ron Hassinger, emphasized a need for contractors and state representatives to work together to improve specifications and promote the use of recycled materials. The discussion concluded with future action items to create specifications that could be harmonized between regions, thus encouraging the use of recycled industrial materials.

Barriers of Recycled Material Use and Current Standardization

The main concerns with US's current system for standardization are the many variations in specifications used within states and the limited communication between transportation, environmental and industry representatives. AASHTO and ASTM material specifications are adopted throughout the US, although each state conforms to its own variation of the standard, if mentioned at all. With varying state requirements, there are barriers within the market to allow similar materials to be used between states. Additional costs for testing and altering the material may be required for each state's varying product specifications, potentially leading to costly mistakes made during the production and distribution phases.

Since only a small number of states have demonstrated successful use of a limited amount of individual materials, only a portion of the region has specifications and regulations in place for less commonly re-used recycled materials. People are also discouraged to attempt new projects using these materials, concerned they may be blamed if something goes wrong [RMRC 2010]. This stems from a lack of experience with some materials and lack of an understanding of the long-term environmental effects.

1.4 Objective of Thesis

The purpose of this thesis is to construct a procedure that guides states in the US to prioritize recycled material specifications within highway applications for regional harmonization. It will be a proactive method to promote the recycling of industrial by-product materials, including the collection, organization, comparison, and evaluation of relevant data on industrial material specifications and their use in highway applications throughout regions in the US. Recycled material standard harmonization promotes compatibility of product specifications, potentially avoiding mistakes and misunderstandings within production and construction, benefiting material source managers economically with the ability to produce consistent products region- or nation-wide

Harmonization will make the use of recycled materials more routine within the states, reducing the demand for virgin materials and landfilling. By diminishing the need for mining natural materials and producing less of energy-intensive products, less carbon dioxide emissions (CO_2) may enter the atmosphere, potentially improving product quality and the environment. Some by-products may also perform better than the materials being replaced, resulting in reduced maintenance, time, and cost.

Providing documentation for the process of material specification selection for harmonization may result in an additional benefit: its subsequent use by other regions; possibly serving as a model for future analysis of specifications. Harmonization facilitates increased communications and collaboration between state DOTs, environmental regulators, industry, FHWA and the US EPA. Common specifications will make it easier and more profitable for contractors and industry: if materials are processed with the same quality, they could be shipped and used state-to-state without the need for alterations between each.

CHAPTER 2.0 - THESIS FRAMEWORK

DEVELOPMENT OF PRIORITIZATION

PROCEDURE

2.1 Thesis Framework

This topic originated from a project at the RMRC, funded by the US EPA, to compile technical information on pre-selected industrial by-product materials with specifications potentially able to be harmonized among the Mid-Atlantic States.

Chapter 3 details the case study's preliminary harmonization procedure, documenting the general comparative assessment that lead to RMRC's compiled short list of priority materials and recommended highway applications and specifications for review. The chapter outlines Material/Application Fact Sheets (Appendix A) created to organize each state's varying use of the materials and related conforming and required specifications, with benefits and barriers to use. Each state's environmental regulations for the selected industrial by-products were entered into a Microsoft Excel Matrix spreadsheet (Appendix B). The results of both documents were subjectively summarized and analyzed to create a priority short list (Appendix C). The list was the basis for discussion at a working meeting in Baltimore MD, a representative location among the Mid-Atlantic States. One of the conclusions of this meeting was that the agreement to use a modeling and decision-making tool to measure, compare and characterize the potential environmental impacts of each material under consideration.

Chapter 4 recommends conducting a life-cycle assessment, using PaLATE (Appendix D) as a guiding tool to objectively compare and assess the differing environmental impacts, enabling the ranking of materials and applications. A case study LCA analyzes the top two applications recommended at the working meeting in Chapter 3. The goal of the study is to illustrate how using the PaLATE program to compare materials in similar applications can establish an accurate representation to guide harmonization, requiring minimal information to input into the program, as seen in the PaLATE worksheet results found in Appendix E and F.

Chapter 5 recommends 10 questions used for a prioritization system (Appendix G) to help rank the priority of each material considered per regional state. This accounts for similar significant factors considered when creating the priority short list in chapter 3. The set of questions have responses ranging from negative 10 to positive 10, supporting a side-by-side comparison between different states.

Chapter 6 provides a summarized recommendation incorporating the case study's information. It is compiled into three processes required to aid harmonization, including compilation, communication, and comparison phases. The recommendation then identifies limitations of the procedure created, including steps to be completed for future work on the potential regional harmonization of recycled industrial material specifications.

CHAPTER 3.0 - CASE STUDY: EPA REGION III MID-ATLANTIC STATES HARMONIZATION

CREATING A PRIORTY SHORT LIST OF RECYCLED INDUSTRIAL BYPRODUCT MATERIALS AND APPLICATIONS FOR HARMONIZATION

3.1 Chapter Objectives

The objective of this chapter is to create a general procedure to develop a short list of potential priority materials and applications easiest to harmonize within a given region. The template documents created by RMRC are based on the results from a case study project, provided and funded by the US EPA, discussed in detail in Section 3.3.

RMRC Goals

RMRC's objective of the case study mentioned above was to provide and analyze documentation of EPA's District III (Mid-Atlantic) State's recycled industrial material specifications and develop recommendations for harmonizing their standards. The US EPA asked the RMRC to provide technical support on the background of using each selected recycled materials application in the US and internationally, including research on case studies, engineering characteristics, environmental and economic benefits, and the beneficial use.

US EPA and FHWA's goal was to make safe and appropriate use of recycled materials in highways a common practice by establishing common material specifications throughout the region. The Mid-Atlantic States include Delaware, District of Columbia (DC), Maryland, New Jersey, New York, Pennsylvania, Virginia and West Virginia. Data and comparisons were compiled for coal bottom and fly ash, foundry sand, scrap asphalt shingles, scrap tires, steel slag and blast furnace slag. Though the materials chosen have been previously demonstrated in projects across the country, they are less commonly used materials. Therefore, this project sheds light on potential highway applications where the materials are used.

3.2 Methodology

Overview

Three sets of documents were compiled in this case study: material/application fact sheets describing each state's conformity with the national standards (Appendix A), state-by-state environmental regulation summaries and matrix for visual comparison (Appendix B), and a preliminary priority short list grouping the researched materials and applications by the likelihood of harmonization. These documents were presented and discussed at the May 2010 Specification Harmonization Meeting in Maryland, where state representations identified additional strategies required to harmonize EPA Region III specifications. The meeting concluded with action items for attendees to discuss strategies with state coworkers and determine if harmonization is possible for the state. This case study discussed a general method for recommending the priority materials and applications to harmonize, and a procedure to do so.

Document Compilation

Material/Application Fact Sheets

The first step to meeting EPA and FHWA's objective was to conduct background research on the six selected recycled materials, which considered its origin, engineering characteristics, chemical and physical properties, highway applications, as well as history of performance. The compiled information was guided using the "User Guidelines for Byproducts and Secondary Use Materials in Pavement Construction," found on the RMRC and FHWA websites, based on data from university research, government agencies and industry group's information, including the American Coal Ash Association, National Slag Association, Scrap Tire Management Council, Industrial Resource Council, and Construction Materials Recycling Association, to name a few.

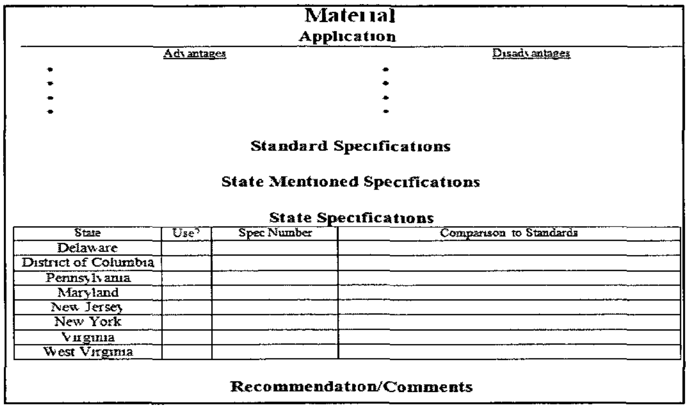
While research on this overview for each material was conducted, Outreach Program Director of RMRC, Jeff Melton sent out a survey to each of the 50 states [Melton 2009], addressing the state's use of various recycled materials and preferred applications, including quantities, if available. Results from the survey gave initial data of common applications for each state across the US. Unfortunately, three of the Mid-Atlantic States (DC, Pennsylvania and Maryland) did not respond, so the resulting data was not completely useful. Additionally, this survey allowed for comments, providing valuable information, including the report of New York's previous use of over 5.6 million scrap tires in recent years, thus exhausting their tire supply.

Mid-Atlantic State road specifications were reviewed using each state's DOT website. These specifications were thoroughly analyzed for similarities and differences between the recycled materials. Information was also found in supplemental specifications, special provisions or permits found on the websites, or through personal contact. Along with AASHTO or ASTM specifications, any other requirements or exceptions were recorded for comparison. Finally, lists of questions were created for each state, noting any confusion or identifying missing data regarding the use and specifications for certain materials.

Each state was contacted, requesting the missing information, leading to the obtainment of more case-specific special provisions or permits, and clarifying the allowed applications and history of use of those materials. Unfortunately, DC never responds to the emails, thus leaving a number of questions for the state unanswered.

Research was subsequently performed to find additional national standards for recycled materials not already mentioned in the state specifications; an example was an AASHTO working item, using foundry sand in asphalt concrete and embankments. This was compared with state specifications to provide an initial foundation of data.

Figure 2 shows the template that was created to organize the information, named "Material/Application Fact Sheets;" each sheet was created for a specific application of the material. It summarized advantages and disadvantages of using the industrial recycled material, related standard and state specifications, allowing for comments or a potential recommendation toward harmonization. Once completed, a matrix was created to summarize the materials and applications reviewed, shown in Table 1. The fact sheets


Material
Application

Advantages	Disadvantages
•	•
•	•
•	•

Standard Specifications

State Mentioned Specifications

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware			
District of Columbia			
Pennsylvania			
Maryland			
New Jersey			
New York			
Virginia			
West Virginia			

Recommendation/Comments

Figure 2 Material/Application Fact Sheet Template

	Cement Concrete	Embankment/ Fill/Sub-grade /Structural Fill	Flowable Fill	Asphalt Concrete	Granular Base Aggregate	Stabilized Base
Bottom Ash		X	X	X	X	X
Fly Ash	X	X	X	X		X
Foundry Sand	X	X	X	X		
Scrap Shingles				X		
Scrap Tires		X		X		
Steel Slag/BFS	X	X	X	X	X	

Table 1 Matrix of Materials and Applications Considering

were sent to the Mid-Atlantic State representatives for review and feedback in advance of the meeting; unfortunately, no responses were received.

State-by-State Environmental Regulation Summaries and Comparison Matrix

Each regional state's environmental regulations for the beneficial use determinations (BUDs) of industrial byproducts were compared, guided by individual solid waste management regulations and programs. Once a material has obtained a BUD, it is no longer considered a solid waste and may be beneficially reused in certain applications. Summaries created of each state's requirements (including where to find the regulations), are found in Appendix B. After a conference call with a US EPA representative, Mary Hunt, a list of common topics among the regulations were compiled and documented in a Microsoft Excel worksheet matrix, comparing environmental regulations state-by-state; this matrix is also found in Appendix B.

Material/Application Priority Short List:

The final document requested before presenting and facilitating the Specification Harmonization Working Meeting in May of 2010 was a material/application priority short list, compiled based on following factors pertaining to an industrial byproduct:

- History of use and performance throughout the Mid-Atlantic States
- Conformity and availability of specifications and environmental regulations
- Source availability and distance to each state

The priority short list included a section for materials most likely to be harmonized (labeled "Yes"), those requiring more testing, research and discussion (labeled "Maybe"), and those unlikely to be harmonized (labeled "No"). This list guided the Specification Harmonization Meeting to select a handful of materials and applications for potential harmonization; this document is found in Appendix C. Once updated data was compiled and sent to Mary Hunt, presentations were created for the meeting to give the participants a visual aid to harmonization procedure.

3.3 Task 1: Recycled Materials Background

Fly Ash

More than 70 million tons of coal fly ash (CFA) is produced annually in the US [ACAA 2006]. When pulverized coal is burned in a dry-bottom boiler - the most common method - approximately 80% of the ash waste exits the furnace as CFA [Horiuchi et al 2000]. Class F and class C are the two most common types of ash used in highway applications. Class F CFA is created by burning older, hard coal that requires a cementing agent, such as hydrated lime, to enhance its cementitious properties when mixed with water. Class C CFA originates from the burning of younger coal containing pozzolanic properties. Since class C contains significantly more lime (15-30%) compared to class F (less than 10%), it will harden and gain strength with the addition of water, making class C a self-cementing material [EPA 2005a]. CFA is made of fine-graded spherical particles, similar to the size of silt, where class C is coarser. Class C also has a light tan color due to the low amount of carbon and the presence of calcium and lime, while class F is often a gray color; lighter ashes correspond to higher quality. A significant chemical property in CFA is the loss of ignition (LOI), which is the residual carbon resulting from the burning of ash, typically from 5-6%.

CFA can be used for a number of highway applications, including: portland cement and asphalt concrete, flowable fill, stabilized base or embankments. In concrete, flowable fill, and stabilized bases, CFA is used as a supplementary cementitious material (SCM), allowing partial replacement of Portland cement. Its spherical shape improves workability and decreases permeability, enhancing its long-term strength. In asphalt concrete, CFA is used as mineral filler, which is comparable to limestone dust, reducing the potential of asphalt stripping [FHWA 2003, Zimmer 1970].

When used in embankments, CFA reduces the need for natural aggregates due to its higher void ratio and greater hydraulic conductivity than fine-graded soils, requiring less compaction. Additionally, CFA performs similarly to granular borrow in terms of settlement and leachate [Collins et al 1989], The main concern with CFA is the potential for trace elements leaching into and contaminating the groundwater, mainly in un-encapsulated applications, such as embankments and stabilized bases. Portland cement and asphalt concrete are considered encapsulated; therefore, very low trace elements leach out similar to concentrations of metals of conventional soils [Churchill et al 1999].Overall, studies show that leachate from coal ash in contact with the water table doesn't migrate far and are at a low concentration in terms of EPA standards [Tandon & Picornell 1998].

Bottom Ash

Over 18 million tons of bottom ash is generated per year in the US [ACAA 2007]. Similar to CFA, bottom ash is also a coal combustion by-product (CCB), created when burning coal, captured as the remaining 20% of the ash left in the furnace. Bottom ash is coarser and heavier than CFA, acting as a stronger aggregate used in embankments, structural fill, flowable fill, mineral filler, bases and anti-skid material. As an angular material with a higher carbon content and lower specific gravity compared to conventional aggregates, it is more porous and beneficial for un-encapsulated drainage applications. Though this characteristic results in a stiffer aggregate, its porous properties may degrade the roadway due to periodic loading or compaction. EPA does not list bottom ash as a hazardous material, stating no significant risk to human health or the environment [Tandon & Picornell 1998]. Bottom ash is most commonly used for embankments and has been beneficially used since the mid-1900's [ACAA 2007].

When used in asphalt concrete, potential issues with pyrite particles have arisen, leading to an unstable and expansive aggregate. These formations do not occur in embankments, thus explaining why it is the most common application. Additionally, the low pH and high salt content may influence corrosiveness within some applications.

Foundry Sand

Foundries purchase virgin sand for casting molds to generate primarily iron, steel and aluminum. The foundry sands are used numerous times until it is deemed unsuitable from excessive heat and mechanical abrasion; the state of physically degraded sand is called spent foundry sand (SFS). Approximately 6 to 10 million tons of SFS is generated annually in the US, but less than 15% is recycled, while the rest is put in landfills [EPA 2007]. There are currently around 2200 active foundries in the US where iron and steel production is prevalent, including Pennsylvania [NFFS].

SFS is higher quality than conventional sands, finely graded, and used as a partial replacement for applications requiring fine aggregate. New sand and binder is often added to the SFS to maintain the quality of the sand; FHWA reports that SFS performs as well or better than quarried or natural soils [FHWA 2004]. Since EPA states that it is rarely hazardous [EPA 2007], SFS may be used in asphalt concrete, cement concrete, flowable fill, embankments, bases, or sub-bases. Typically it contains bentonite clay, potentially providing better compaction and freeze-thaw performance [Guney at al 2006].

Concerns related to using SFS are its potential environmental effects and hydrophilic properties. This means it attracts water to its surface, increasing the probability of stripping the asphalt concrete pavement, thus requiring anti-stripping agents and increasing costs. With respect to the leaching of metals and organic compounds of concern, environmental studies have shown that SFS's leachate concentrations are generally at a low level [Ham et al 1993, Winkler et al 2000, Wang 2000, EPA 2007] therefore, more feasible to use if locally available. However, it was determined that it has moderate potential to inhibit growth of freshwater algae [Nelson et al 2000].

Scrap Asphalt Shingles

With a total of approximately 11 million asphalt shingle scraps generated per year in the US [EPA 2005b], its use in pavements has evolved and increased over the last 25 years. Shingles contain between 16 to 25% asphalt cement and are impregnated by either glass or organic felt fibers to increase its strength [Owens Coming 2000]. The two types of scrap shingles used are tear-off and tabs; pre-consumer tabs are created while trimming shingles during manufacture, while tear-off shingle scrap are post-consumer construction and demolition (C&D) waste, containing debris such as nails, wood, paper or plastics. Tabs are more commonly used because they are homogeneous and free of debris. Since shingle scrap is of high market value for asphalt content, it is typically used in hot-mix asphalt (HMA).

The fibers within the shingles function like mineral filler, creating a stronger and stiffer pavement, ultimately reducing the thickness and compaction of the pavement layer required. The stiffer pavement improves resistance to rutting and lowers low temperature cracking. There may also be a cost benefit if the savings of replacing asphalt cement exceeds the costs to process the scraps. A case study with the Iowa DOT explained that shingles helped control dust, was cost efficient and created a quieter roadway [Marks et al 1997].

The main concern with tear-off shingle scrap in HMA is the potential for asbestos to be present. This issue remains even though EPA has required testing regulations from the National Emission Standard for Hazardous Air Pollutants (NESHAP) and most TCLP testing does not show asbestos or is well below EPA's hazardous waste limits [Krivit 2007]. Shingle manufacturers also have detailed specifications to deal with asbestos if it is an issue.

Scrap Tires

Of the approximately 300 million tires are generated per year in the US; 13% are landfilled, 53% are used as tire derived fuel, 12% are used for civil engineering projects and 17% are used as crumb rubber. Regardless of these statistics in 2007, 180 million tires are still stockpiled across the US [RMA 2009]. Scrap tires are commonly used to generate electricity because of their high energy density, but can also be used as a tire-derived aggregate (TDA) for asphalt concrete (ground and crumb rubber) and embankments (shredded and chipped tires).

When used for chip seal or surface treatment in HMA, the rubber increases the viscosity of the asphalt, resisting reflective cracking better and allowing for a reduction in the pavement thickness [RMRC 2010]. Because of insulating properties, scrap tire chips respond well to temperature change, performing better and reducing the depth of frost penetration compared to conventional pavements when used as fill or subgrade material [Humphrey & Eaton 1993]. Scrap tires have been used within embankments in over 70 successful projects in the US [Humphrey 1996]; it is just as permeable as coarse granular aggregate and very economical compared to borrow [Epps 1994].

It is commonly used as a lightweight aggregate, and successfully used on weak soils. It has been shown that 75 tires are equivalent to one cubic yard of aggregate [Humphrey & Sandford 1993] for embankments, allowing for a large quantity of tires to be used at one time. One challenge with scrap tires is a lack of knowledge of the resulting environmental effects due to varying rubber composition and production procedures. Therefore, its performance and characteristics vary dramatically, creating a challenge for quality conformity and control of the material.

It has been documented that the heavy metals and organic concentrations leaching out is negligible [Tatlisoz et al 1996]; but because of the high viscosity, there have been recorded issues with storing the tires and pumping the asphalt ["User Guidelines for Byproducts and Secondary use Materials in Pavement Construction"] and concerns for material and compacting consistency, potentially leading to differential settlement. On the other hand, a South Carolina case study found that the asphalt rubber mixture through the wet process increased the tensile strength and performed better than the control mix [Amirkhanian 2001].

Steel and Blast Furnace Slag

Approximately 8 million tons of steel slag, a by-product of steel-making, is generated and marketed for use per year in the US [Proctor et al 2000]. It is formed when separating molten steel from impurities, done with either basic oxygen, electric or open-hearth furnace. Its three grades, related to carbon content, range from smallest to largest (Grade 80, 100 and 120).

Steel slag is used as an aggregate in asphalt concrete, granular bases and embankments; it is generally known to be a comparable aggregate in respect to durability, having high friction qualities and skid resistance properties [Emery 1982]. However, it also has a high absorption rate, requiring more asphalt cement, increasing the weight and cost for material transportation. Free lime and magnesium oxides within the steel slag cannot react with the silicate structure of cement; therefore, the material will hydrate and expand in humid temperatures. This has become a huge concern among the states, but is solved by stockpiling the materials up to 18 months to allow it to expand and leach before use.

Blast furnace slag (BFS) is formed from a blast furnace and cooled by either *ambient temperatures (air-cooled BFS) or pressure water sprays and crushed (ground* granulated blast furnace slag [GGBFS]). Air-cooled BFS forms a crystalline structure and can be an aggregate for fill, embankments or bases. GGBFS is glassy sand but does not form a crystalline structure. It has cementitious properties, and therefore is used as a SCM in concrete and flowable fill. Using GGBFS reduces the heat of hydration and resist alkali silica reaction (ASR) and sulfate attack. It can also reduce carbon dioxide (CO_2) emissions and energy needed to calcine limestone for use in concrete.

Both steel slag and BFS are non-metallic angular aggregates that have been shown to reduce energy use and associated green house gas emissions from the avoidance of limestone or the replaced natural aggregate extraction. Additionally, its use as an aggregate may reduce water use and air pollution [EPA 2008, Kiggins 2009, van Oss 2008]

3.4 Task 2: Mid-Atlantic States Use, Specifications and Environmental Regulations

Delaware

Delaware's Solid and Hazardous Waste Management Branch (SHWMB) regulates the beneficial use of C&D debris, CCBs, and scrap tires. Currently, the state requires written approval to beneficially use an industrial material, including proposed processing methods, equipment, and its marketability. It does not have a specification for regulating beneficial use but Delaware is creating a guidance document for BUDs [RMRC 2010].

The state has never been requested to beneficially use bottom ash, steel slag, tear-off shingles, and SFS but allows the use of CFA, BFS, scrap shingle tabs and scrap tires in highway applications. The most typical use of CFA in Delaware is portland cement concrete, followed by flowable fill as a special provision, and embankments, a less common application (done once in the mid 1990's [Pappas 2010]). Scrap asphalt shingle tabs used in HMA are allowed by special provision while tear-off scrap shingles have never been requested by industry for use. Scrap tires are a special provision in HMA, surface treatment and embankments; they have only been used in HMA once but they are currently working on another project [Pappas 2010]. BFS is used for asphalt concrete, concrete, and flowable fill as a special provision.

District of Columbia

DC lacks any specifications for beneficial reuse of industrial materials available, but the state allows CFA and BFS in their highway applications. Since there is a lack of foundries in DC, there is no source of SFS. CFA is allowed in concrete, flowable fill and stabilized base, and only as mineral filler for asphalt concrete when approved by a Chief Engineer. BFS is used in portland cement concrete and as an aggregate for asphalt concrete. Scrap tires have been used in sidewalks [dcdot.com] and work well in this application.

Maryland

Maryland has regulations for the beneficial use of both scrap tires and CCBs, and is currently working on a proposed specification for the beneficial reuse of CCBs, used in cement or asphalt concrete and bottom ash as an aggregate for portland cement concrete, asphalt concrete, flowable fill and anti-skid material. This proposed regulation will include leachability testing and monitoring of the CCBs. The Department of the Environment also runs the Tire Cleanup and Recycling Fund to promote the use of tires in highway applications [mdot.maryland.gov].

Maryland uses CFA, scrap shingles (tabs only), steel slag and BFS in highways, but industry has never requested the use of bottom ash, SFS or scrap tires [Davis 2010]. CFA is used for concrete, flowable fill, and mineral filler. It is not, however, allowed in stabilized bases due to the potential leaching of un-encapsulated applications significantly concerning the Chesapeake Bay, where most groundwater drains [Davis 2010]. Steel slag is only allowed in chip seal surface treatment in asphalt concrete while BFS is only used in concrete, but does not have a specification for slag-blended cement.

New Jersey

New Jersey provides a guidance document including beneficial use regulations and project approval processes for pre-determined materials and case specific requirements. Pre-determined materials include tires as a road aggregate and CCBs in concrete, asphalt, and sub-bases. Documentation and quality assurance procedures are required, while case-specific projects require letters from the generator and receiving facility, certifying the material with testing procedures.

CFA, scrap shingles, scrap tires, and BFS are regulated in New Jersey but industry has never asked about the use of bottom ash or SFS [Sheehy 2010]. The concrete and asphalt industries have stated that they do not want to deal with using steel slag in any of their products [Sheehy 2010]. CFA is used in portland cement concrete, flowable fill, and mineral filler in asphalt concrete. CFA hasn't been used in stabilized bases for over 20 years [Sheehy 2010] but New Jersey keeps it as an option; it is not used in embankments because the state finds fill cheaper and easier to use. NJ Department of Environmental Protection (DEP) is too concerned with asbestos to allow tear-off shingles in HMA but they do allow the use of tabs [Sheehy 2010]. Tires are used in HMA but they have only completed one job for its use in embankments. Though the DOT forced the contractors to use them, the workers claim that it is more trouble than it is worth [Sheehy 2010].

New York

New York (NY) has regulations for pre-determined BUDs as well as case-specific materials and applications. Pre-determined materials include tires as aggregate for bases and asphalt, CFA in flowable fill and CCBs in concrete and structural fill. Case-specific projects require chemical and physical characteristic testing, and proof of marketability and its meeting of DOT specifications.

NY regulates CFA, scrap tires, and BFS. Bottom ash has never been requested for use, while SFS is not used because no source warrants its use [Orayfig 2010]. The state is open to a pilot project [Melton 2009] using shingles in HMA but producers report they have difficulties reaching consistent mixes. Though tabs are allowed, tear-off shingles are not because the cost to clean them outweighs the benefits [Orayfig 2010]. CFA is used in concrete and flowable fill, but is not used for mineral filler, even though a specification is available. Stabilized bases haven't been constructed in NY for over 20 years [Orayfig 2010], thus there is no specification even though the use is not prohibited. Plans for using CFA in a number of embankments projects were all canceled for various non-environmental reasons [Orayfig 2010] so the application is a new concept to them; steel slag is also not permitted to be used in highways. Due to the state's limited availability of asphalt binder scrap tires are used in asphalt concrete and require a special provision for embankment use, even though NY has substantial experience with TDA embankment projects, exhausting the state's supply of tire stockpiles [Melton 2009]

Pennsylvania

Pennsylvania has regulations for pre-determined BUDs, case-specific, general permits as well as running a Waste Tire Recycled Program. Pre-determined BUDs include CCBs for structural fill and cement concrete, and bottom ash as an anti-skid material. This requires plans, material volumes and chemical and leaching analysis. The general permits are used for scrap shingles, scrap tires, steel slag and SFS.

Pennsylvania has specifications for bottom ash (only in flowable fill), CFA, SFS, scrap shingle, scrap tires, steel slag and BFS. CFA is also used for flowable fill, concrete, stabilized base and mineral filler in asphalt concrete. SFS may be used for HMA and flowable fill, and only embankments under a general permit. Scrap shingles require a permit are used in HMA, cold-mix asphalt (CMA), sub-base and dust control. Under a special provision and general permit, scrap tires may only be used in HMA, but Pennsylvania is currently pending for the use of TDA in embankments [RMRC 2010]. Steel slag is allowed as an aggregate in asphalt concrete under a general permit. There are specifications for BFS used in concrete and flowable fill but a permit is required to be used as a granular base.

Virginia

Virginia has environmental regulations for scrap tires and CCBs, including pre-determined and case-specific BUDs. Pre-determined BUDs include CCBs in cement concrete, flowable fill, sub-base, embankments or bases, scrap tires in sub-base fill or drainage material, and bottom ash as surface or anti-skid material. Case-specific materials and applications require waste control and emergency plans, chemical and physical characteristics and periodic testing such as a TCLP test for CCBs.

Virginia has specifications for bottom ash, CFA, shingles tires, and BFS. Bottom ash is only allowed in flowable fill under a special provision. In embankments, Virginia is concerned with the toxic metals within the material and when getting EPA's Department of Environmental Quality (DEQ) to sign off on its use; the regulations and monitoring required is more effort than they want to invest [Clark 2009]. CFA is used in concrete, stabilized bases, embankments and flowable fill under a special provision. It is not allowed as mineral filler in asphalt concrete because of concern with it degrading under compaction [Clark 2009]. SFS is not used because Virginia does not have large steel operation, so sands are not available in large consistent quantities. Both tabs and tear-off scrap shingles are allowed in HMA under a special provision, while tires are allowed in HMA on a case-by-case basis since no specification is currently available. Tires in embankments must be permitted by a special provision. Steel slag is not used in highway applications, but BFS is used as aggregate for asphalt concrete, cement concrete, granular base, SCM, and flowable fill under a special provision.

West Virginia

Under the Solid Waste Management Rule, West Virginia has beneficial use regulations for CCBs, as well as pre-determined BUDs and permits. Pre-determined materials include CCBs in cement concrete, flowable fill and a proposed regulation for structural fill. Bottom ash an anti-skid material and tires (less than 100) in sub-bases and embankments are also pre-determined materials. The permits in place are for C&D debris and tires, requiring a report of the proposed use and material volumes, market analysis, fire plan and dust control for tires, as well as annual updates from groundwater leachate testing.

West Virginia allows the use of bottom ash, CFA, steel slag and BFS in their highway applications. Bottom ash was initially used more frequently, but they stopped using it in un-encapsulated applications, except for embankments which must be cleared by the DEP [Gillispie 2010]. Bottom ash is allowed in flowable fill, but considered case-by-case. CFA may be used in flowable fill, concrete and asphalt concrete. It was used more frequently as mineral filler in asphalt concrete, but now their asphalt plants use bag houses which provide all the dust required for HMA [Gillispie 2010]. CFA was used in embankments but West Virginia was recently persuaded by environmental leaching claims to review the application; therefore, it is now considered on a case-by case basis [Gillispie 2010]. SFS and shingles are not used because the state does not have enough supply to establish a specification [Gillispie 2010]. Steel slag may be used as an aggregate in surface treatments and HMA, while BFS is used in granular bases and concrete, SCM or aggregate.

3.4 Task 3: Comparison and Analysis of Mid-Atlantic State's Material Specifications

Industrial material specifications are first analyzed using the Fact Sheets to clearly present the differences and similarities within the Mid-Atlantic States. Each material is discussed and analyzed in this section of the chapter to give a better understanding of how RMRC created the priority short list of materials and applications potentially used for harmonization among the regional states.

Bottom Ash

Bottom ash is one of the least common materials used in this region's highway applications, as shown in Table 2. Though the most common application among the states is flowable fill, both Virginia and West Virginia are concerned with the materials leachability and fear that it contains toxic metals. Therefore, this material was not included in the priority list because not enough states showed interest, even though it has been shown that bottom ash has a lower potential to leach than CFA [industrialresourcescouncil.org].

Application	DE	DC	MD	NJ	NY	PA	VA	WV
Flowable Fill Aggregate						√	√*	√
Embankment Fill/Structural Fill								√
Granular Base Aggregate								
Stabilized Base Aggregate								
Asphalt Concrete Fine Aggregate								

*Special Provision

Table 2 States Mentioning Bottom Ash in Road Specifications

Fly Ash

CFA is the most commonly used industrial material in highway applications and has a long history of use in the US and internationally ["User Guidelines for Byproducts and Secondary use Materials in Pavement Construction"]. According to Table 3, both concrete SCM and flowable fill are the most commonly used applications, though two states require special provisions for flowable fill. Because of the commonality of the applications, the history of its use, and the availability of the material, both were included in the priority short list.

Application	DE	DC	MD	NJ	NY	PA	VA	WV
Cement Concrete SCM	√	√	√	√	√	√	√	√
Flowable Fill	√**	√	√	√	√	√	√**	√
Asphalt Concrete Mineral Filler		√	√	√		√		√*
Stabilized Base		√		√*		√	√	
Embankment Fill/ Structural Fill	√*						√*	

*No spec – Allow use – job specific
** Special Provision

Table 3 States Mentioning Fly Ash in Specifications

Fly ash: Cement Concrete SCM

When looking into CFA as a SCM for concrete, all states conform to the specifications AASHTO M295 and AASHTO M240. The main differences between the states are the maximum LOI and the classes of CFA accepted, shown in Table 4. Most states allow class C and F with the exception of NY, only allowing class F. Though, in this area, Class C is typically not used as successfully due to ASR problems. The LOI's between the state specifications range from 3-6%, while only Virginia has a 5% maximum LOI, matching the national specifications for CFA in cement concrete. Also, all of the states that have BUD programs have included CFA for use in concrete.

States	Classes of Fly Ash Allowed	Maximum LOI %	BUD
DE	C & F	4%	
DC	C & F	4%	
MD	C & F	3%	√
NJ	C & F	3%	√
NY	F	4%	√
PA	C, F & N	6%	√
VA	C & F	5%	√
WV	C & F	6%	√

Table 4 Differences in Fly Ash in Concrete

Fly ash: Flowable Fill

Similar to CFA in cement concrete, the main difference in this application is also the maximum LOI, shown in Table 5. All departments allow the use of CFA in flowable fill, while three states do not require any regulations for its use. All conform to AASHTO M295, but only three of the states changed their LOI maximum, including Virginia, which does not require a maximum. Both Delaware and Virginia require special provisions and have created their own specifications, which may be helpful since AASHTO

States	Max LOI	BUD
DE	4%	
DC	4%	
MD	3%	
NJ	3%	
NY	4%	√
PA	16%	
VA	No Max	√
WV	12%	√

Table 5 Differences in Fly Ash in Flowable Fill

does not have a general specification for flowable fill

Foundry Sand

SFS is only common used in Pennsylvania (shown in Table 6 (on the next page) because of the foundries available within the state, however SFS is only allowed from sources listed on their website [dot state pa us] Most states do not mention SFS, due to either never being asked to use the material or a lack of large steel operations within the state Because of this, the material was considered low priority and not used for the priority short list

Application	DE	DC	MD	NJ	NY	PA	VA	WV
Asphalt Concrete Aggregate						√		
Embankment Fill/Structural Fill						√*		
Flowable Fill						√		
Cement Concrete Aggregate								

* Requires General Permit

Table 6 States Mentioning Foundry Sand in Road Specifications

Scrap Asphalt Shingles

Scrap Shingles HMA

Shingles were found to be used, mainly by special provision, by five of the states, where 40% allow both tear-off and pre-consumer tabs while the remaining 60% allow only tabs, shown in Table 7, on the next page This is mainly due to of the cost for processing and a concern of asbestos Because of this common concern, testing

States Mentioning Scrap Asphalt Shingles (Tabs) in Road Specifications

Application	DE	DC	MD	NJ	NY	PA	VA	WV
Asphalt Concrete Aggregate and Binder	√*		√	√		√*	√*	

* Special Provision or General Permit

States Mentioning Scrap Asphalt Shingles (Tear-off) in Road Specifications

Application	DE	DC	MD	NJ	NY	PA	VA	WV
Asphalt Concrete Aggregate and Binder						√*	√*	

* Special Provision or General Permit

Table 7 States Mentioning Asphalt Shingles in Road Specifications

precautions are taken for the processing of the shingles to reduce the possibility of asbestos presence, though most studies have shown that asbestos is not present [Krivit 2007]. Since the cost savings of using less asphalt cement may outweigh the cost to process the shingles, there may be an economical benefit for using shingles in HMA. Two specifications were created directly for reclaimed asphalt shingles (RAS): AASHTO MP15: Specification for Use of RAS as an Additive in HMA and AASHTO PP53: Standard Practice for Design Considerations when Using RAS in new HMA. More than half of the states allow the use shingles in HMA, so this material was included in the priority short list for discussion.

Scrap Tires

Application	DE	DC	MD	NJ	NY	PA	VA	WV
Asphalt Concrete	√*			√	√***	√*	√***	
Embankment/Fill	√*				√	√**		

*Special Provision or Requires General Permit
** Pending for Use
*** No spec but Uses

Table 8 States Mentioning Scrap Tires in Road Specifications

Scrap tire availability is always constant as vehicles are used and disposed of in all states across the US. Even though scrap tires in asphalt concrete are used in two more states than in embankments, shown in Table 8, the performance of its use varies dramatically. Further, impacts on the environment and its ability to resist cracking are still unclear. Due to these considerations, tires in asphalt concrete were not included in the list of priority materials, but its use in embankments was.

Scrap Tires: Embankment/Fill

Most specifications for tire use in embankments are special provisions, but are allowed in two of the Mid-Atlantic States. Others have never been presented with this application or view them as more trouble than they are worth. New York has a tire shred initiative in place to use TDA for embankments. As shown in Table 9, this application has a national specification, ASTM D6270: Standard Practice for Use of Scrap Tires in Civil Engineering Applications currently used in only Delaware. NY has experience with tires but has exhausted its supply, having used over 5.6 million tires used in embankments from 2003-2008 [Melton 2009]. While Virginia and West Virginia do not have specifications, they both allow chipped tires to be beneficially used with approval for use in embankments. The lightweight properties and ability to be used on weak soils may make them more profitable than borrow, and are easy to use, which is why the material and application has been included in the priority short list.

States	Mentions use In Road Specs	Conforms to ASTM D6270	BUD
DE	√	√	
DC			
MD			
NJ			
NY	√		
PA			
VA			√
WV			√*

* Only if under 100 tires are used

Table 9 States Use of Scrap Tires in Embankments

Steel Slag

Steel Slag: Asphalt Concrete Aggregate

For states that allow the use and require a maximum expansion, the percentage varies from 0.5% to 2.5%. Initially, Maryland's requirement was 1.5% but since this could not be reached, the maximum was increased to 2.5% [RMRC 2010]. Stockpiling time requirements also vary from three months to two years, requiring costly tests for quality assurance. Though these are significant challenges, steel slag as an asphalt concrete aggregate is common practice in Europe [Schimmoller 2000] and can be done in an efficient way. The specification, ASTM D5106: Standard Practice for Steel Slag Aggregate for Bituminous Paving Mixtures addresses its use and ASTM D4792: Standard Test Method for Potential Expansion of Aggregates from Hydration Reaction addresses the expansive issues with slag used as aggregate. As shown in Table 10, none of the states conform to ASTM D5106, but Pennsylvania has developed its own specification to deal with the expansion of steel slag for use as aggregate, using it safely and efficiently.

State	Use Mentioned in Road Specification	Conforms to ASTM D5106	Conforms to ASTM D4792
DE			
DC			
MD	√*		√
NJ			
NY			
PA	√		
VA			
WV	√		

* Only allows chip seal surface treatment

Table 10 States Use of Steel Slag as Asphalt Concrete Aggregate

Blast Furnace Slag

BFS is the second material with the largest use among the states, with GGBFS specifications for concrete as a SCM or blended cement being the most common application. Although five states have their own specifications for air-cooled BFS in concrete, shown in Table 11, only three of the states actually use the material for the application. Since other applications are less commonly used and do not have standard specifications pertaining to its application, only GGBFS used in concrete was added to the priority short list.

Application	DE	DC	MD	NJ	NY	PA	VA	WV
Cement Concrete SCM	√	√	√*	√	√	√	√	√
Flowable Fill	√**					√	√	

*Doesn't allow Slag in Blended Cement
** Special Provision

Table 11 States Mentioning Blast Furnace Slag

GGBFS: Portland Cement Concrete SCM

When analyzing the use of GGBFS in concrete the main difference found between the Mid-Atlantic States is the grade of slag allowed permitted, illustrated in Table 12. DC is the only state that does not allow Grade 100 slag while NY does not allow Grade 120; what is used in West Virginia is still unknown. The specifications for this application are AASHTO M302: Standard Specification for Slag Cement for Use in Concrete and Mortars and AASHTO M240: Standard

States	Grades of Slag Allowed
DE	100 & 120
DC	120
MD	100 & 120
NJ	120 (100 with approval)
NY	100
PA	100 & 120
VA	100 & 120
WV	Unknown

Table 12 Differences in GGBFS in Concrete

Specification for Blended Hydraulic Cements. All of the states allow the use of GGBFS as a SCM in concrete, but Maryland is the only state that does not conform to the blended cement standard.

Summary of Results

This is the final priority short list of material and applications for discussion at the May 2010 Specification Harmonization Working Meeting. The order of this list ranges from those most likely to be harmonized to those that should be harmonized, but may require further discussion. This summary table is shown below in Table 13.

Material	Application	Specification
Coal Fly Ash	Cement Concrete Flowable Fill Structural Fill/Embankment	AASHTO M295, AASHTO M240 ASTM E1266 ASTM E2277
Ground Granulated Blast Furnace Slag	Cement Concrete	AASHTO M240 AASHTO M302
Steel Slag	Asphalt Concrete Aggregate	ASTM D5106 ASTM D4792
Scrap Tires	Embankment	ASTM D6270
Scrap Shingles	Asphalt Concrete (HMA)	AASHTO MP15 AASHTO PP53

Table 13 Priority Short List of Materials/Applications for Specifications Harmonization

3.5 Task 4: Facilitate Harmonization Specification Working Meeting

Overview

Once all documents were compiled, the US EPA and FHWA organized a working meeting at the Maryland State Highway Agency on May 25th, 2010 where RMRC facilitated the discussion on the primary materials and applications to harmonize among the states. Participants included representatives from each state's transportation and environmental departments, as well as members of the EPA, FHWA, and RMRC.
The RMRC gave a series of presentations covering the priority materials and documents compiled. The meeting targeted a review of documents on state material specifications and environmental regulations; this opened the discussion to identifying appropriate modifications to any of the documents, and identification of additional strategies important to harmonize the specifications. The meeting concluded with a list of action items for each priority material and application for the states to bring back to their office and discuss with local staff. The following sub-sections report the meetings findings for each discussed material and application on the short list.

Although SFS was not on the priority list of topics, it was discussed, noting the presence of foundries within Pennsylvania and West Virginia. DC does not have any foundries and, therefore, does not use SFS as an aggregate. Delaware, on the other hand, has plenty of fine aggregate to spare, so the use of SFS would not be feasible for that state.

Priority Material/Applications:

1. Fly Ash as SCM in Portland Cement Concrete and Blended Cements
2. Fly Ash in Flowable Fill
3. Ground Granulated Blast Furnace Slag in Portland Cement Concrete
4. Steel Slag as Aggregate in Asphalt Concrete
5. Scrap Tires in Embankments
6. Fly Ash in Embankments/Structural Fill
7. Scrap Shingles in Hot Mix Asphalt

Fly Ash: Cement Concrete SCM and Blended Cement

The US EPA began the discussion by reminding the participants about the recent Coal Ash Rule pertaining to its disposal. It was noted the rule would not affect the beneficial use of CFA in highway applications and EPA highly supports beneficially reuse.

The main topics discussed for this application were the maximum LOI and the class of CFA allowed. If class C can be included in NY's specifications, then that portion of the specification can be harmonized to allow both classes C and F of CFA.

If it is not too complex to reduce the maximum LOI, then consideration should be taken to reduce the LOI to 4%.

The group discussed that the LOI is controlled by the producers and processors; since there is no contract between the state and the producers, the option of creating specifications for the industry could make it feasible to harmonize specifications, especially AASHTO M295 and AASHTO M240. A proposed specification for the producer should include best practice methods to make the use more profitable for the supplier and easier for shipment with a common LOI.

Since Delaware has only one plant that produces CFA, they import it from

Separation Technologies LLC, which supplies consistent and durable high quality CFA and eliminates the issue of a consistent supplier. Jim Pappas stated there are other companies that could be used in a similar manner. Delaware is also developing a new specification (summer 2010) that targets high performance concrete and requires a SCM to be added for all concrete applications.

Discussion concluded by requesting all states to investigate the reasoning for their LOI criteria and to discuss changing the percentage to 4 or 5%. Pennsylvania was asked to look into the reasoning for the 5% maximum specification, while NY researched why Class C CFA is excluded from their specifications.

Fly Ash: Flowable Fill

The discussion started with mentioning a lack of AASHTO or ASTM specifications for flowable fill, though both Pennsylvania and Virginia have created their own specifications along the same lines as SCMs used in concrete.

According to Virginia DOT's Larry Lundy, the maximum LOI in this application does not matter because air-entraining agents are not necessary, so Virginia created a special provision bases the use of CFA on strength development and performance. Pennsylvania recently wrote a specification with four different types of strength, depending on application, including CFA and other SCMs that could be used. DC DOT's Wasi Khan mentions that the state bases it use of flowable fill on set time, though they have had issues with fill seeping into foundation cracks.

The conclusion of this discussion is to look into Pennsylvania's flowable fill specification and share it among the states to potentially create a common specification all states can follow, based on strength and set time. A new specification would need to include a set time with a focus on performance rather than LOI. Another idea arose to open the specification to all states in the US, using an equivalency method that would be quantitatively determined based on where the state location.

Discussion concluded asking Pennsylvania to provide their flowable fill specification to share with the Mid-Atlantic States and to join West Virginia in clarifying why their LOI changed to what it is now.

GGBFS: Cement Concrete SCM and Blended Cement

When analyzing the use of GGBFS in concrete or blended cement, the main difference found was the grades of slag allowed. Participants told the group that industry guarantees Grade 100 slag, but approximately 90% to 95% of the time, the industry is supplying Grade 120 slag. This slight variation permits an increase in performance without a significant increase in cost. DC DOT's Wasi Khan mentioned that using Grade 100 slag causes problems with permeability, explaining the state's lack of use, though Jim Pappas emphasized that the performance is practically as good. The group concluded that allowing both Grade 100 and 120 would be a simple transition.

Maryland is the only state that does not allow blended cements, which is a result of a slow transition into using recycled materials. The DOT is currently looking into slag use for pre-stressed concrete but is open to adopting the blended cement standard, at their availability. The specification for blended cements only came out in 2009, so it was not surprising that one state has not yet conformed to the specification. The percentage of slag allowed was the final topic discussed but was quickly dropped for a lack of consistent availability within the states.

Discussion concluded with Maryland looking into allowing GGBFS within its blended cement and concrete specifications. Additionally, DC was to look into allowing Grade 100 slag, while NY looked into allowing Grade 120 slag.

Steel Slag: Asphalt Concrete Aggregate

The main issues found with steel slag as an aggregate are its expansive tendencies and the lack of interest to hydrate and test the material, assuring it has fully expanded and leached out contaminants while stockpiled.

Each state handles steel slag in a different way and none of the states use the national specification, ASTM D5106, pertaining specifically to steel slag as an aggregate in bituminous pavements. Delaware assumes that all steel slag is reactive, following the specifications of the Texas DOT. Maryland has only completed one project blending steel slag and natural aggregate, and after 10 years, the performance is still good. NY requires a certification process that includes hydrating, stockpiling, and testing the steel slag pile to determine when the slag is ready to be used. Since this is an encapsulated application, New York uses steel slag in asphalt concrete, and records that it works well according to the TCLP testing; although concerns have arisen with chromium in steel slag fines, it is still allowed to be used in driveways, un-encapsulated. Pennsylvania also requires expansion testing, though the results for slag vary. Since steel slag is high in absorption, the state has found problems with freeze-thaw when the material retains water. Pennsylvania is currently working on experimental projects to learn more about its conductively corrosive behavior. Virginia has a time limit to stockpiling steel slag, but has found problems with a high pH. Overall, the participants are all willing to work with steel slag as an aggregate, but more discussion is required to make this possible.

Discussion concluded with the recommendation to develop a certification test for slag prior to its use and include this information in a mapping tool to acknowledge the location of certified steel slag. Pennsylvania was asked to review the differences in its Testing Methods (PTM) and ASTM expansion test and provide the AASHTO survey on use of steel slag

Scrap Tires: Embankment

All of the participants are amenable to using scrap tires in embankments; the issues are the necessity for time to stockpile and test as well as tires availability. It was mentioned that it takes time to stockpile, test, and shred tires and most users do not want to wait for the material to be ready. A large volume of tires may also be required for some projects as a minimum and if they are primarily used for energy recovery, fewer tires are available for embankments.

Again, each state has a different way of handling the tires, if at all. Delaware has one tire processing facility and also has a scrap tire initiative, promoting its tires in a number of civil engineering applications. Unlike most states, Delaware does not allow the burning of tires, so they have greater availability for use in applications such as embankments (even acknowledging the recommended specification ASTM D6270), though the state primarily uses them for septic systems. NY also is well known for using scrap tires, though they recently exhausted their stockpiles. But as always, additional tires continually become available as they are discarded from vehicles. However, New York also requires a $2 tipping fee to recycle tires; this fee could hinder the beneficial use of scrap tires in that particular state.

While the DC and Maryland have never had the opportunity to use scrap tires for embankments, DC has used them in sidewalks; thus far, it has shown good performance. Unfortunately, both states lack stockpiles of working materials, but they are both willing to begin using tires in experimental projects.

Pennsylvania mentioned a job using over two million tires that was canceled, which left the state with a large number of tires and uncertainty of what to do with them. Therefore, tire storage may become a problem for environmental agencies. The DOT states that the excessive steps to screen tires add to the cost of using them, and recognize is a potential lack of space needed for storage. Virginia has used tires in embankments and recalled one project, analyzed by using monitoring wells, that has yet to see leachate. The state allows tires to be stockpiled for a long period of time, but at a certain point, requires a permit to continue its storage; this also requires a cleanup fee, hindering the material's use.

The conversation concluded asking all states to look into conforming to ASTM D6270 and start using scrap tires more regularly.

Fly Ash: Embankment and Structural Fill

Unfortunately, time ran out during our meeting before we could discuss the topic of CFA in embankments or structural fill, though a number of environmental leaching concerns with this un-encapsulated application may hinder its potential harmonization.

Scrap Asphalt Shingles – Asphalt Concrete and HMA

Time also ran out before we could discuss the topic of scrap shingles in asphalt-related applications. The only mention of shingles was explaining that the fibers within them add strength and decreases the thickness required for the pavement.

Meeting Conclusion

The meeting concluded with each state agreeing to complete their action items for a conference call planned for the week of July 10, 2010. These items were to be discussed and the next steps for harmonization to follow.

3.6 Case Study: Final Recommendation

After discussing the priority materials and applications at the GHP Specification Harmonization Working Meeting, it is clear that CFA and GGBFS are the easier materials to harmonize due to their common use and application in highways. CFA in concrete and flowable fill would be the easiest applications to harmonize among the Mid-

Atlantic States by coming to a common LOI maximum and allowing both class C and class F ashes. Though, it should be taken into consideration that class C is less commonly used in the Northeast due to issues with ASR. Issues include AASHTO's lack of a flowable fill specification so the states should look to Pennsylvania to guide them to a common specification. GGBFS in concrete would also be an excellent application to harmonize by allowing the use of Grade 100 and 120 in the application. Also, Maryland should adopt the blended cement specification, AASHTO M240.

Scrap tires in embankments is a common use but some states are less experienced with the material than others. Additionally, the national specification is only used by one state; therefore, more discussion is required for harmonization of this specification among the Mid-Atlantic States. It is clear that the application will work but will be more challenging than CFA or GGBFS.

Steel slag as an aggregate in asphalt concrete is also a common application among a number of states nationally and internationally, though this material requires more discussion and testing before the Mid-Atlantic States will be comfortable harmonizing this specification and using the material in flexible pavement. Finally, asphalt shingles used in HMA is becoming more common; however, more time, research and discussion is required before the Mid-Atlantic States may harmonize the specifications. From the previous section, Table 13 shows the priority materials and applications along with the specification that should be used to harmonize among the Mid-Atlantic States.

3.7 Limitations

While this case study reduced the various amount of priority materials and application for harmonization, it did not develop a tool for ranking the options to guide regional decision-making. The team also realized that it took much more time to come to a simple agreement than expected as all states were unclear why their specification required certain maximums or tests. Additionally, a number of states' material providers had never brought up the concept of using some of the mentioned recycled materials, and lacked an economic reason to use the material. This means that each recommended material needs to have a usage incentive to get participants interested in using the product and also need to obtain a better understanding of the reasoning behind their specifications.

CHAPTER 4.0 - THE LIFE-CYCLE ASSESSMENT

A DECISION-MAKING TOOL FOR PRIORITIZATION COMPARISON

4.1 Introduction

There are a number of phases a product within a highway application experiences including: material extraction and processing, product manufacturing, transportation, construction, use, maintenance, and disposal or recycling at the end of its life [ISO 2006a, 2006b], as shown in Figure 3. Each phase within the life-cycle creates environmental burdens which may either directly (pollutant emissions) or indirectly (cancer potential) impact the environment for various periods of time. Since these impacts vary by case, life cycle assessment (LCA) studies analyze the variables within the life cycle of a product and calculate resulting environmental loadings due to unit processes.

The previous case study detailed in Chapter 3 recommended either CFA or GGBFS specifications for concrete to harmonize use among the Mid-Atlantic States. The study is based on individual state specifications and experiences with industrial byproducts; however, the methodology lacks comparative environmental data.

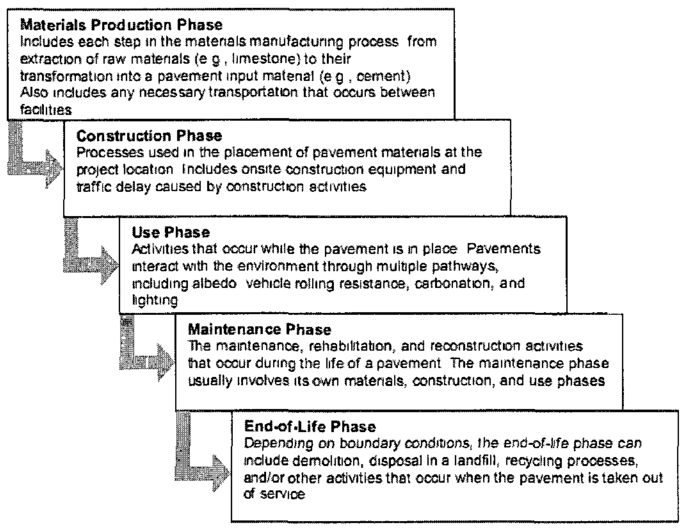


Figure 3 Typical Roadway Life Cycle Phase Diagram (Santero 2009)

4.2 Objective

The chapter's objective is to exemplify the capability of a LCA method to rank potential material/applications for regional specification harmonization. The LCA assesses environmental effects (air emissions, ground contamination, and resource consumption) that correspond to different phases throughout the product's life. It can be used to compare and interpret some interactions between emissions of a product's unit processes in similar applications and the effected environment. This enables officials to view aggregated impacts to using various recycled materials and makes more informed decisions about which material, recycled or not, should get priority for use in highway applications [Stripple 2001].

This chapter will discuss a modeling tool that may be beneficial for prioritizing materials used within pavement-specific applications. A LCA case study follows, demonstrating the program's ability to compare the environmental burdens between three concrete mix alternatives: two industrial byproduct mixes and one control with natural virgin components. A New Hampshire project site was chosen based on accessibility of information.

The following list of questions is answered throughout the chapter:

1. How do the recommended industrial byproduct concrete mixes, (concluded in Chapter 3), environmentally compare to conventional concrete mixes?
2. How do the environmental loadings change when the production and transportation phases are considered separately? (in accordance with Section 4.4)
3. Does this LCA example help guide decisions for recommendation of prioritized material/applications list for harmonization within a region of states?

4.3 LCA Framework

LCA methodology is standardized by the ISO, focusing on four phases [ISO 2006]: a goal/scope, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation of the results, illustrated in Figure 4.

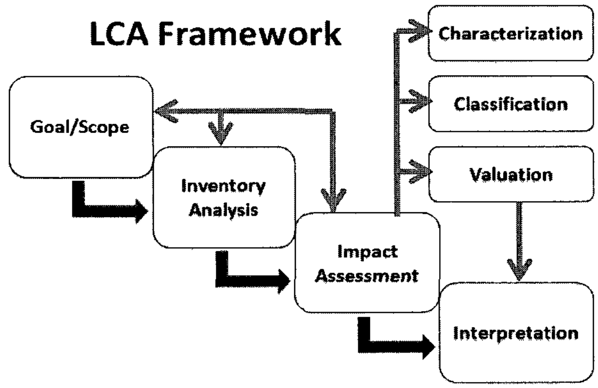


Figure 4 Typical LCA Flow Diagram

The goal states the objective of the LCA, the audience, stakeholders involved, and how the results will be used. The scope includes project details, a common unit (functional unit) for comparison, general assumptions, and limitations of processes or emissions included in the analysis (the system boundaries). The LCI reports and references process specification assumptions and emission factors, allowing for a comparative analysis of each product considered. The LCIA converts environmental loadings into environmental impacts, dividing the overall results into appropriate impact categories for comparison.

During the interpretation phase, the LCI and LCIA results are compared within the scope to interpret outcomes and highlight main sources of emissions and uncertainties within the characterization model. The process is cyclic and reiterates until the goals are met.

LCA Modeling Tool

In order to conduct a comparative LCA of materials in highway applications, the Pavement Life-Cycle Assessment Tool for Environmental and Economic Effects (PaLATE) [PaLATE 2003] worksheet was used containing its own data inventory, outputting environmental economic life-cycle impacts (Appendix D). Appendix D-1 documents the program's inputs and outputs, following with emission sources (Appendix D-2), and factors assumed (Appendix D-3). The program was created in 2003 by the Consortium on Green Design and Manufacturing team from the University of California, Berkley under contract to the RMRC, and is the only pavement LCA available in the US, evaluating virgin and recycled materials in highways using Microsoft Excel, capable of being easily edited by users.

PaLATE bases its environmental loading factors using an economic input-output (EIO) LCA method [Hendrickson 2006], which traces the direct and indirect environmental and economic inputs and estimates the economic-wide environmental burdens from various processes of the product within a period of analysis. The EIO-LCA approach divides production facilities and services into approximately 500 sectors, covering the entire economy. PaLATE gives a "semi-industrial system level analysis" [Carpenter 2007], including the following unit processes: raw material extraction, material processing and manufacturing, on and off-site construction equipment, repair and disposal of a product. The next section demonstrates the use of PaLATE in a case study using recycled and virgin materials.

4.4 Case Study: Comparative Analysis of CFA, GGBFS and Virgin Material in a Concrete Deck

Goal

The goal of the case study is to analyze and compare environmental burdens of the production and transportation of CFA and GGBFS concrete mixes with a virgin material concrete mix, illustrating a decision-making tool with environmental loadings only. Using a reference mix allows the industrial materials to be compared to common natural material, giving an environmental incentive when the recycled material concretes emit lower emissions. This analysis will also assist in identifying major environmental burdens within each system process and driving forces to the environmental loadings.

The audience of the LCA includes decision-making representatives from the US EPA, FWHA, states DOTs, and environmental departments influencing recycled material specification approval for roadways.

Scope

Project Details

NHDOT began a test project in 2010, on a New Hampshire Route 107 bridge over Griffin Brook at the Epsom/Deerfield border, illustrated in Figure 5. The bridge requires reconstruction from earlier damage of floods from 2007 [NHDOT 2008], replacing the concrete deck using CFA and GGBFS within in the mix.

Volumes and densities of materials used in the three mixes are found in Table 14, using 1 cubic yard of concrete, with a compressive strength of 4000 pounds per square inch (psi), as a functional unit.

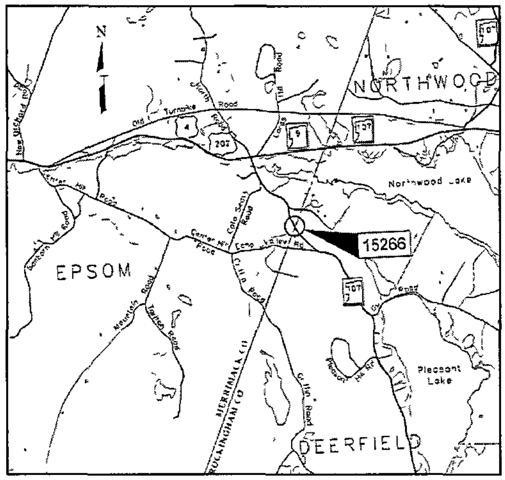


Figure 5 Project Site Map Deerfield/Epsom NH

Material	Density (tons/yd^3)	Fly Ash Mix Volumes (yd^3)	GGBFS Mix Volumes (yd^3)	Virgin Mix Volumes (yd^3)
Aggregate	2 23	0 693	0 649	0 594
Cement	1 27	0 867	0 0604	0 1444
Fly Ash	2 2	0 0204	-	-
Blast Furnace Slag	1 72	-	0 0652	-
Water	0 84	0 1485	0 1707	0 202
Chemical Admixture	1	0 02	0 02	0 02
Air-Entraining Agent		0	0 01	0 01
Total Concrete	2 03	1 005	1 007	1 001

Table 14 Mix Designs of Concrete Cases for Functional Unit

System Boundaries and Assumptions

As a comparative study, similar processes between alternative options are disregarded from the analysis [Stripple 2001], focusing on major differences between the materials and procedures within a product's life. The study assumes the construction, use and maintenance for all three mixes are similar in process and performance [McDonald 2010]; therefore, are removed from the calculations to simplify the data.

Typically, materials taking up less than 5% of the total mass are not significant enough to require inclusion from the study [ISO 2006]. Due to the diminutive and similar volumes of both air-entraining agents and chemical admixtures within the three mixes, the concrete additives are removed from the analysis. The calculations for weight percentages using GGBFS concrete are found in Appendix E-3, exemplifying that the additives serve only approximately 0.04% of the whole mix, smaller than water (7.5% of the mass).

Simplifying the data further, PaLATE does not include emissions from the production of any byproduct that would have otherwise been landfilled as a result of the original product's manufacturing [Mroueh 2001]. In other words, environmental impacts from GGBFS and CFA are not considered in this study. It is a "cradle-to-gate" analysis, only including processes directly related to the materials incorporated in the functional unit. These include material extraction, transportation, or processing, as well as the manufacturing or transportation of concrete to the project site, detailed in Figure 6, indicating the flows of inputs and outputs within the product's system. Only the transportation of industrial materials is included, making the phase and material source location a significant factor to the outcome of environmental loadings.

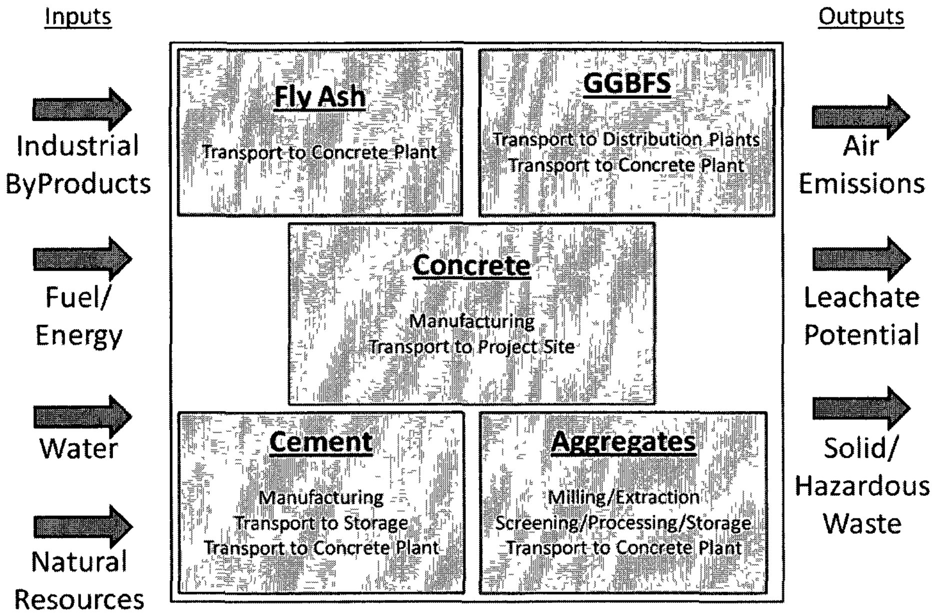


Figure 6 Inputs and Outputs within the System Boundary

Though PaLATE considers the operation of both transportation vehicles and production equipment, it ignores the manufacturing and transportation of individual equipment to the job site. Since environmental loadings are the main interests for this study, the outputs recorded include CO_2 emissions, energy and water consumption, and additional potential toxic air and ground contamination, detailed in Appendix D-1.

Limitation/Uncertainties

A LCA cannot give 100% clarification for how future generations will be environmentally burdened by the processes in the product's lifetime, so only assumptions can be made about the indirect environmental impacts that could appear later [ISO 2006].

Since the study bases its results on values and calculations embedded in the PaLATE program, the assumptions influence the LCA in terms of production equipment, diesel engine characteristics, process techniques, material characteristics and calculation methods. There are also uncertainties and errors from data source reporting and aggregating emissions into impact categories, shown in Figure 7.

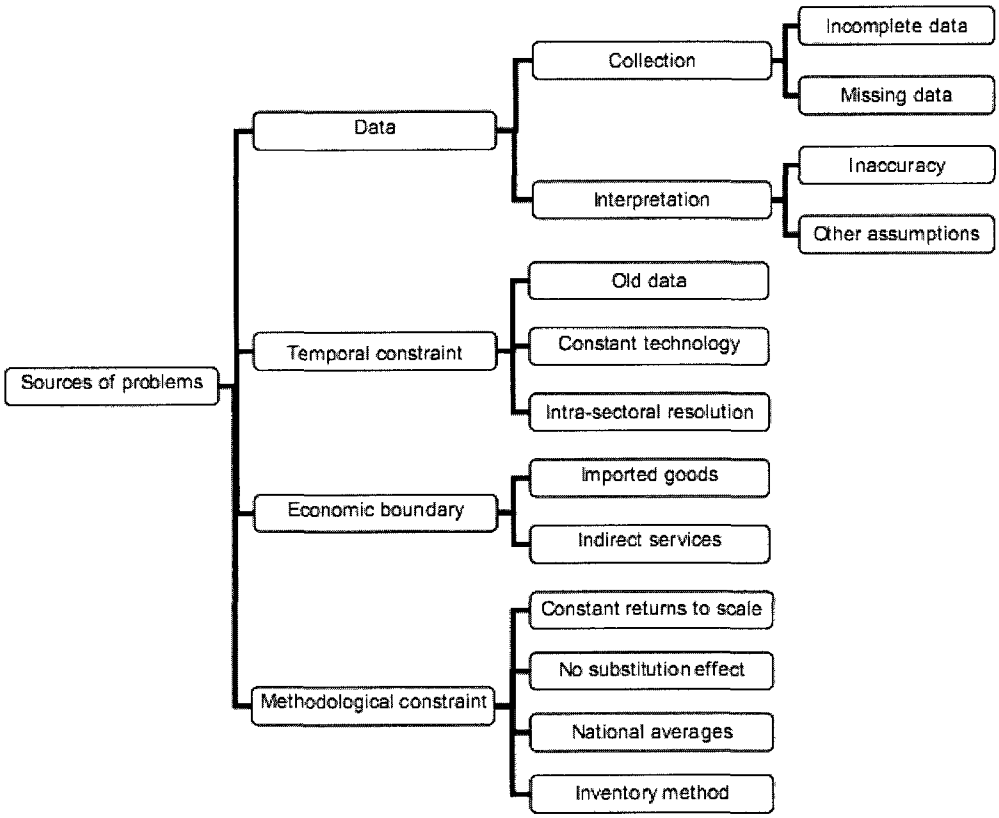


Figure 7 Sources for Error within EIO-LCA approach (Pacca 2002)

Life Cycle Inventory (LCI)

Introduction

The LCI describes the flows of materials and energy in and out of the product system, defined by the system boundary, from the previous section. This section breaks down the assumptions of data on the system process emissions, consumptions, and references.

Environmental Loading Emission Factors & Assumptions

The various environmental outputs and their sources are summarized in Table 15; the references per phase are detailed in Appendix D-2.

Envrionmental Loading	Unit	Source
CO_2 Emissions	kg	EIO-LCA 1997, Means 1997, OECD 1997, U.S.EPA
HTP (Cancer or Non)	g	Morse 2003, U.S. EPA
Energy Consumption	MJ	EIO-LCA 1997, Means 1997, OECD 1997
NO_x Emissions	g	EIO-LCA 1997, Means 1997, OECD 1997,
PM_{10} Emissions	g	FIRE, EIO-LCA 1997, Means 1997, OECD 1997,
CO Emissions	g	EIO-LCA 1997, Means 1997, OECD 1997,
SO_2 Emissions	g	EIO-LCA 1997, Means 1997, OECD 1997,
Pb Emissions	g	EIO-LCA 1997, Means 1997, EPA TCLP
Mg Emissions	g	EIO-LCA 1997, Means 1997, EPA TCLP
RCRA Hazardous Waste Generation	g	EIO-LCA 1997, Means 1997,
Water Consumption	g	EIO-LCA 1997, Means 1997

* FIRE - EPA's Factor Information REtrieval - http://www.epa.gov/ttn/chief/software/fire
* Means - R.S. Means Building Construction Cost Data
* OECD - Organization for Economic Co-operation and Development
* TCLP - Toxicity Characteristic Leaching Procedure

Table 15 References for Environmental Loadings Considered

As the only factor not referenced by the EIO-LCA emission factors, human toxicity potential (HTP) is calculated within the program, estimating the potential harm of a unit of chemical being released, based on toxicity data, and shown in Appendix D-3. It assesses both carcinogenic and non-carcinogenic potentials by converting toxic emissions into a common unit, such as benzene (for carcinogenic HTP) and toluene (for non-carcinogenic HTP). HTP values due to material production is calculated based on the potential of metals within the materials to leach into the surrounding soils and reach groundwater level (primarily lead and arsenic). However, this approach does not account for retardation of contaminents in sub-surface materials [Morse 2003], which helps prevent significant contaminants to transport to water sources, illustrating a limitation of the PaLATE program. HTP values associated with transportation are due to toxicity of air emissions from engine exhausts.

PaLATE's emission factors are broken down by transportation vehicles (truck, rail barge), detailed with sources in Appendix D-3, and summarized in Table 16. The factors are based on equipment properties, including productivity rate, fuel consumption, fuel type and engine size obtained from the manufacturers.

Transportation mode	Fuel efficiency	Capacity	Energy [MJ/l]	CO2 [g/l]	Nox [g/Mg-km]	PM-10 [g/Mg-km]	SO2 [g/Mg-km]	CO [g/Mg-km]
dump truck	0.420 l/km	20 Mg	35.8	2678.90	3.00	0.585	0.180	0.25
tanker truck	0.420 l/km	20 Mg	35.8	2678.90	3.00	0.1700	0.180	0.25
rail	0 705 l/km_Mg	1 Mg	35.8	2678.90	0.400	0.0700	0.180	0.15
barge	1.027 l/km_Mg	1 Mg	35.8	2678.90	10.57	0.1838	0	0
cement truck	0.420 l/km	23 Mg	35.8	2678 90	3.00	0.5848	0.180	0.25
truck	**23**	**Btu/vehicle-mile**	source: http://www-cta.ornl gov/cta/data/Download22 html					
railroad	**35**	**Btu/ton mile**						
waterborne commerce	**51**	**Btu/ton mile**						
diesel motor fuel	**128,700**	**Btu/gal**						

Table 16 Emission Factors due to Various Modes of Transportation

Material-Specific Emission Flows and Assumptions

The sub-section reports sources for each material assumptions for emissions resulting from material production and transportation, with the exception of production CFA and GGBFS emissions, which is assumed zero. Hauling modes and distances from material sources are the main factors inputted to calculate transportation emissions (besides equipment characteristics, mentioned above). Table 17 summarizes the variables included in the analysis, varying by mix volumes.

	Source Information	Hauling Distance (mi) (Mode of Transit)	CFA Mix Volume (yd^3)	GGBFS Mix Volume (yd^3)	Virgin Mix Volume (yd^3)
Concrete	Redimix Concrete: Bow, NH	21.5 (Truck)	1.005	1.007	1.001
Cement Type II	Ciment Quebec, Inc: Quebec, Canada	466.5 (Rail)	0.867	0.0604	0.1444
Fly Ash	Headwaters Resources, Inc: Somerset, MA	118 (Truck)	0.0204	0	0
GGBFS	Sparrows Point Slag Granulation & Grinding Plant: Baltimore, MD Lefarge North America: Baltimore, MD Lefarge North America: Charlestown, MA	12 (Truck) 522.8 (Barge) 60.8 (Truck)	0	0.0652	0
Coarse Aggregate	Pike Industries & Hooksett Crushed Stone: Hooksett, NH	5.1 (Truck)	0.4044	0.400	0.394
Fine Aggregate	Fillmore Industries, Inc Loudon, NH	17.4 (Truck)	0.289	0.249	0.1993

Table 17 Material Source Transportation Variables

As the concrete manufacturers, Redimix Companies Inc provides the concrete mix reports (Appendix E-1), including each material source. A more detailed table of material source contact information can be found in Appendix E-4. Since New Hampshire does not allow virgin-only concrete mixes in their deck projects, [Hall 2010] a virgin mix design is include and calculated following the American Concrete Institute's Standard ACI 211.1-91; Appendix E-2 gives assumed variables inputted and resulting outputs by mix volume and weight.

Cement is assumed to be railed the entire distance from the manufacturing plant to the concrete plant, ignoring the 1.4 miles of trucking from the storage facility. As a result, the rail distance was increased by the trucked miles. In the case of GGBFS transportation, the program was run twice: once using the transportation distance associated with the barge mode of transit and a separate analysis for only the transportation distance associated with trucking in between. It is also assumed that water is obtained on-site so a transportation distance is not included. Table 18 shows the overall environmental loadings between all three mixes from cradle-to-gate, though a breakdown of the emissions, material by material, is given in Appendix F-1.

	Fly Ash Mix		GGBFS Mix		Virgin Mix	
	Material Production	Transportation	Material Production	Transportation	Material Production	Transportation
Energy (MJ)	1,748	1,985	1,608	4,553	1,986	3,237
Water (g)	698	330	651	767	870	543
CO_2 - GWP [kg]	122	148	112	340	138	242
NOx [g]	1,509	398	1 402	1,261	1,733	372
PM-10 [g]	659	77	624	85	666	71
SO_2 [g]	1,051	36	946	29	1,277	42
CO [g]	834	42	796	36	911	46
Hg [g]	0 00259	0 001399	0 00248	0 00325	0 00281	0 00230
Pb [g]	0 1582	0 0651	0 1478	0 1514	0 1796	0 1072
RCRA Hazardous Waste Generated [g]	2,359	13,956	2 289	32,462	2,431	22,976
HTP Cancer [g]	55	26	55	46	52	42
HTP Non - Cancer [g]	346,798	32,101	331,971	56,801	306,091	51 614

Table 18 Overall Environmental Loadings of Each Case Mix, Cradle-to-Gate

The following set of environmental emissions describes and compares the loadings between the three mixes, by material production or transportation. Each sub-section briefly discusses the PaLATE environmental loadings, in order of their subjectively-weighted importance, mentioned in the next section. Many of the following "material production" graphs exclude CFA and GGBFS due to the emissions lack of inclusion of recycled materials, despite HTP and PM calculations.

Global Warming Potential

Virgin concrete exhibits the highest emissions during production due to a higher volume of cement produced in the mix, explaining the low emissions of GGBFS concrete during production, containing the least volume of cement. Figure 8b shows the emissions due to transportation of the materials alone, where cement transportation is similar to the distribution of Figure 8a, due to the volumes of cement used. Since GGBFS is coming from Maryland, the furthest source from the project site, it is expected that its emissions would be the largest, making GGBFS concrete the least desirable for this project, in terms of GWP, summarized in Figure 8c.

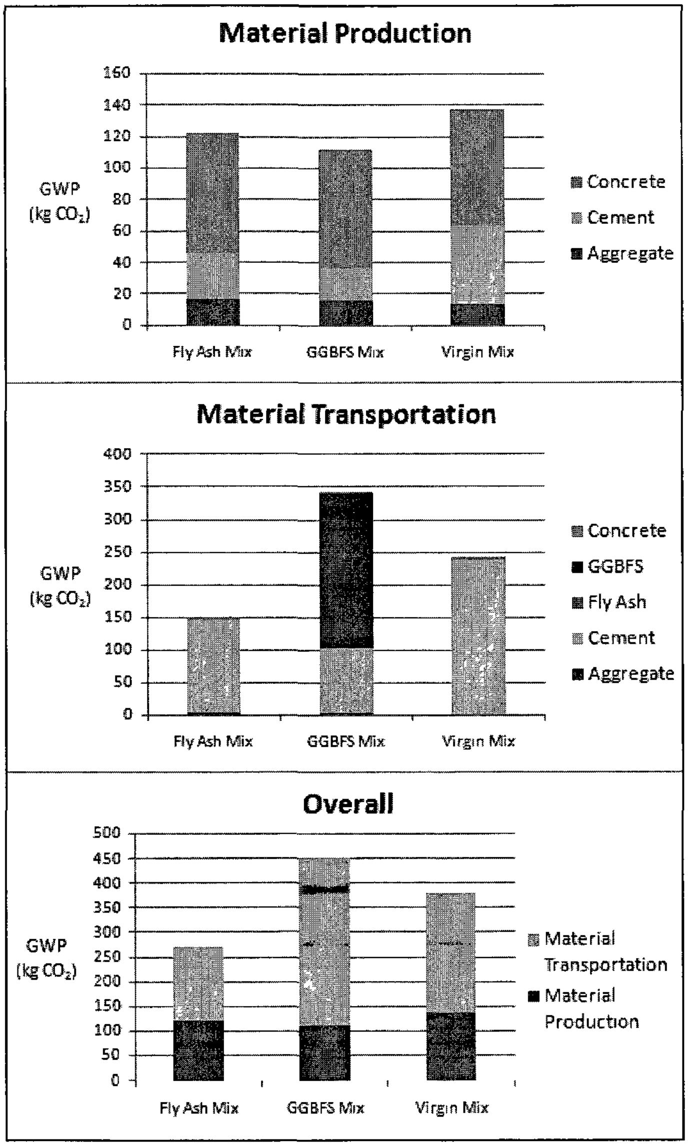


Figure 8 GWP (CO2) Emission Distribution by Material: a) Production, b) Transportation, c) Overall

Energy Consumption

Figure 9a shows the energy distribution during production; the lowest consumption is GGBFS concrete, due to its lower volume of cement within the mix. Figure 9b repeats this pattern with cement transportation.

Though GGBFS is transported using a barge, the program's highest fuel efficient mode of transportation, its large transportation distance (over 500 miles) consumes slightly more energy than double the volume of cement transported in the virgin mix.

Therefore, the overall energy consumption, in Figure 9c, shows the GGBFS mix consuming the most energy of the three mixes due to hauling distance, with the CFA concrete mix using the least.

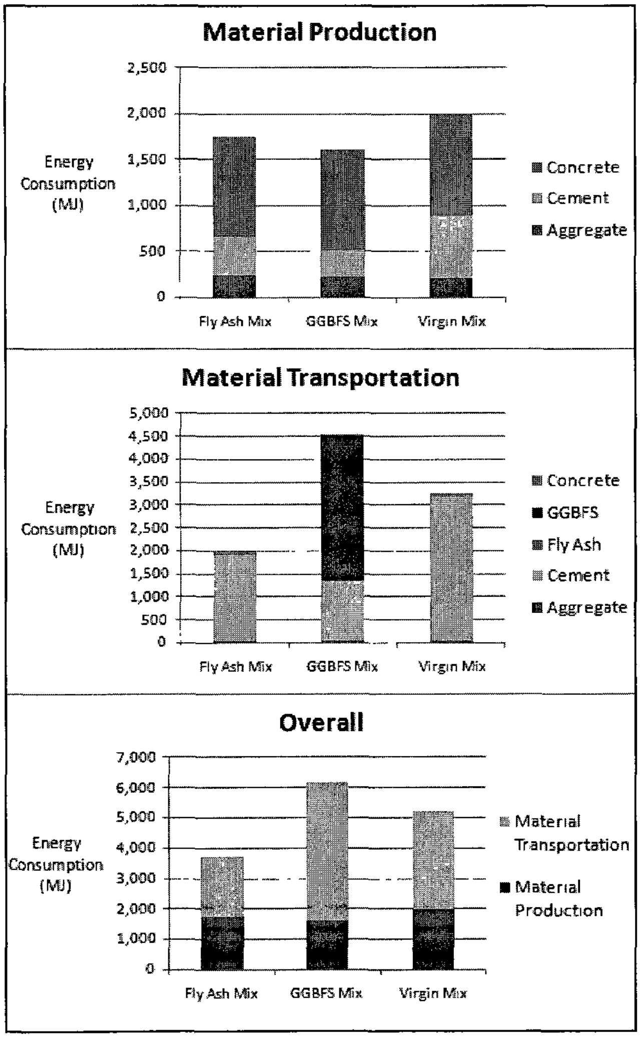


Figure 9 Energy Consumption Distribution by Material: a) Production, b) Transportation, c) Overall

Air Pollutants:

NO_x Emissions

NO_x is produced during fuel combustion at high temperatures ["Nitrogen Dioxide"], explaining the large emissions from concrete manufacturing, followed by cement, illustrated in Figure 10a. Though the transportation distribution would have been relatively equal between all cases, Figure 10b exemplifies GGBFS's barge emissions overwhelming the data. PaLATE's emission factors [PaLATE 2003] due to barge transport are three times greater than that of trucks. Due to this, it is expected that the overall highest emissions for both phases, shown in Figure 10c, is the GGBFS mix, with the virgin mix and CFA mix following thereafter.

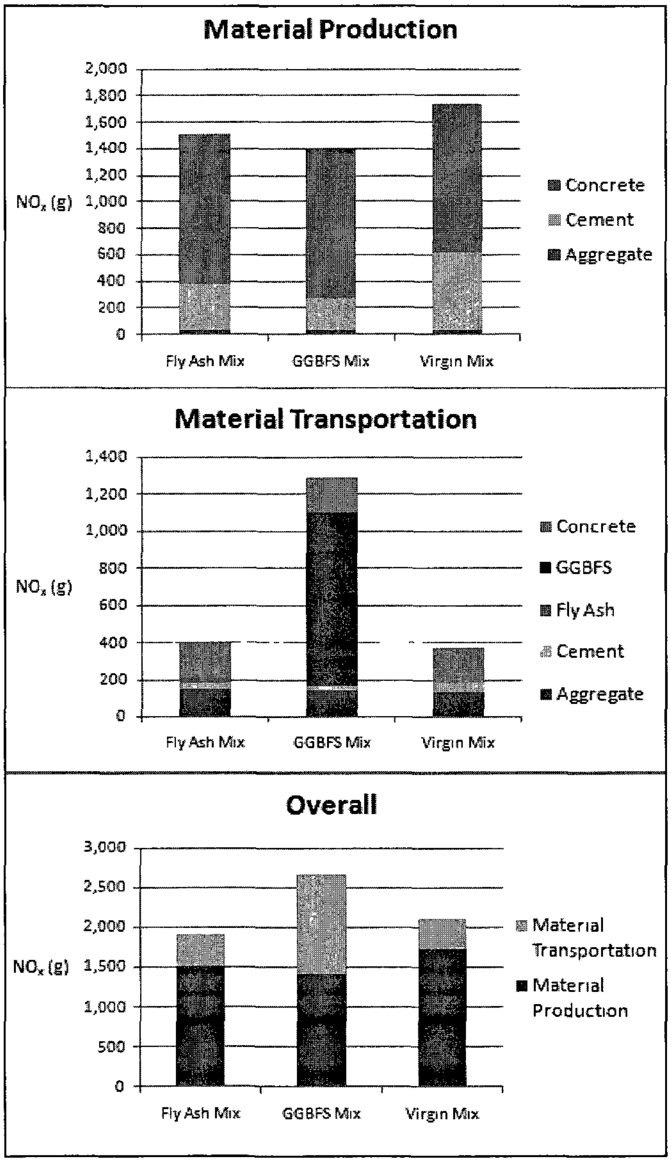


Figure 10 NOx Emission Distribution by Material: a) Production, b) Transportation, c) Overall

PM_{10} Emissions

Particulate matter (PM) is produced from fuel combustion, emitting air pollution primarily during concrete manufacturing and aggregate processing, shown in Figure 11a. The graph does not include CFA sintering because the emissions were insignificant (<1 grams).The emissions between all three mixes are similar, showing both the CFA and GGBFS mixes emit less PM during production than the control virgin mix, with GGBFS concrete having the lowest emissions, overall.

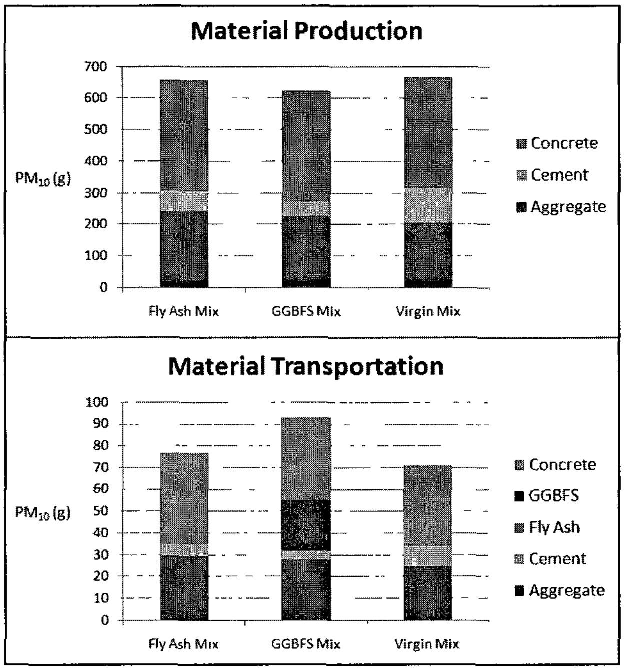


Figure 11 Particulate Matter Emission Distribution by only Material a) Production; b) Transportation

Figure 11b illustrates the variation in PM emissions in material transportation, using an emission factor three times larger for trucks than barges for calculations, explaining GGBFS's small impact. PM in the form of dust is produced when loading trucks and from friction of the tires on roadways. Since more PM emissions are produced during the material production phase, the overall emissions, shown in Figure 12, presents GGBFS concrete as having the lowest emissions, then CFA concrete, demonstrating that the industrial byproduct mixes perform better.

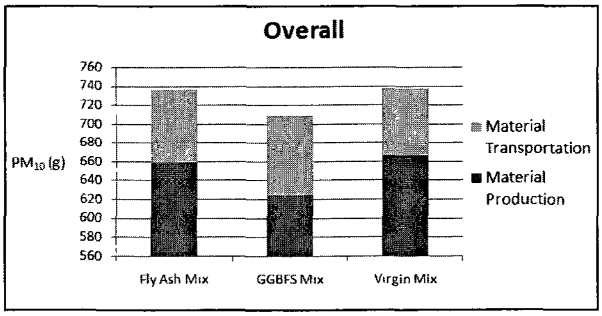


Figure 12 Overall PM Emission Distribution

CO and SO_2 Emissions

Figures 13 and 14 show that CO and SO_2 emissions do not have significant influence on GGBFS barge transportation compared to other emissions, where it differs primarily by cement volumes, leaving the GGBFS mix with the lowest CO and SO_2 emissions in both phases. The CFA mix is the second lowest, meaning both industrial mixes perform better than the conventional mix in terms of CO and SO_2 emissions.

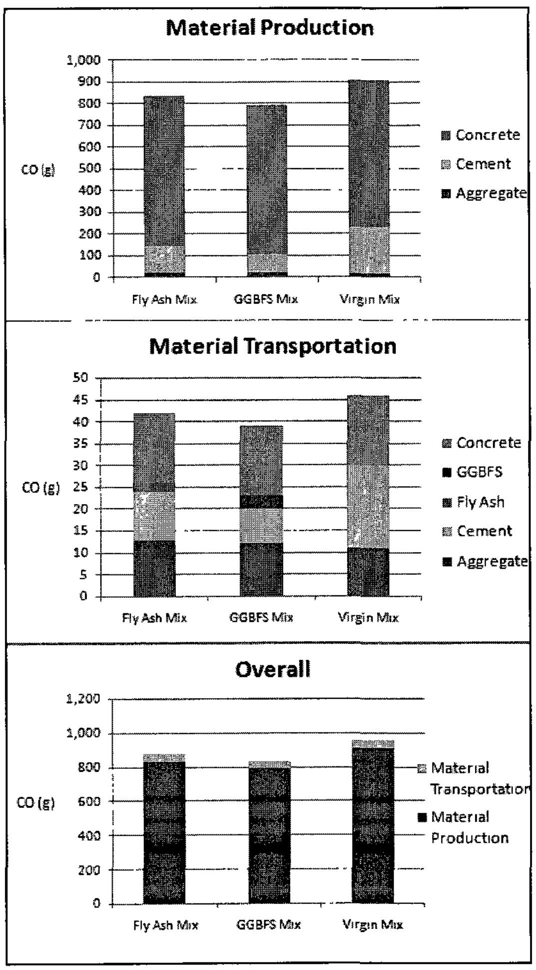


Figure 13 CO Emission Distribution by Material a) Production, b) Transportation, c) Overall

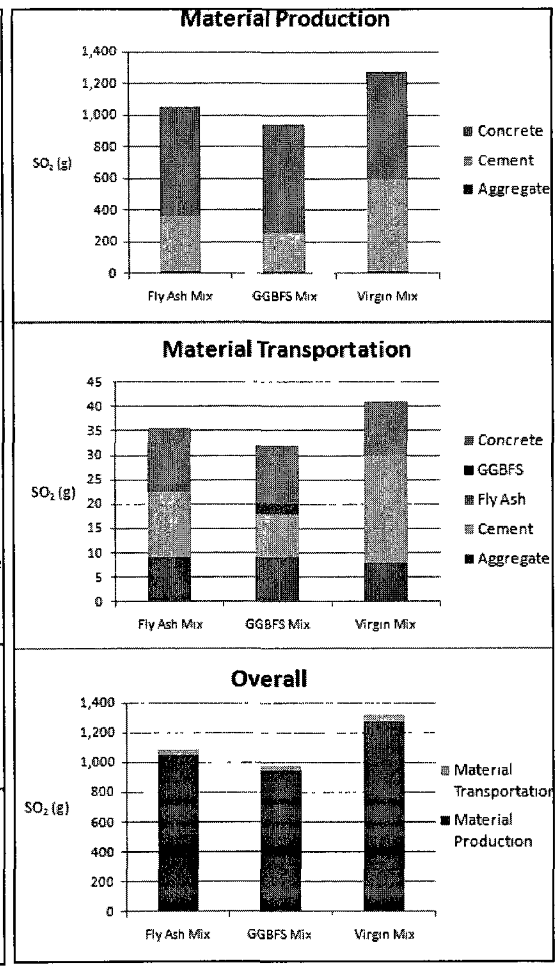


Figure 14 SO2 Emission Distribution by Material a) Production, b) Transportation, c) Overall

Toxic Metals

Lead and Mercury Emissions

Lead and mercury emissions, during material production, are primarily due to concrete manufacturing, and emission values vary due to varying volumes of cement, illustrated in Figure 15. Both cases demonstrate that either industrial case's emissions are below the virgin mix.

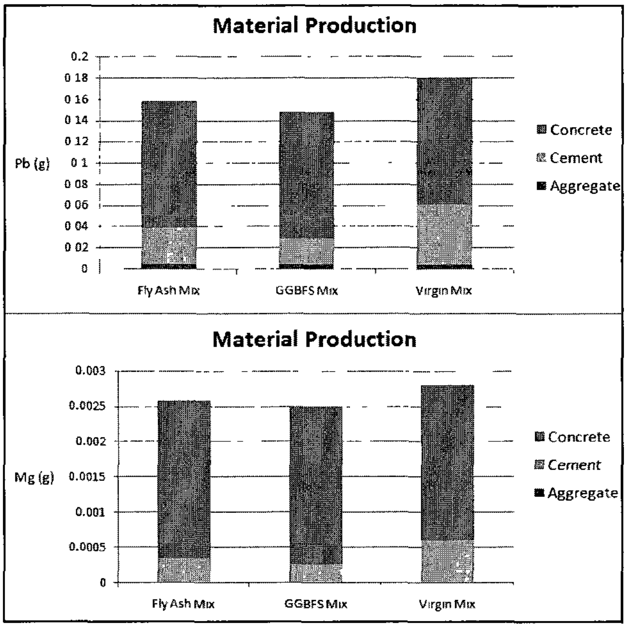


Figure 15 Production Lead and Mercury Emission Distribution

Figure 16 shows that lead and mercury is emitted during the transportation for cement and GGBFS primarily, shipped by rail and barge, respectively. Emissions are potentially due to petroleum leachate from the different modes of transit.

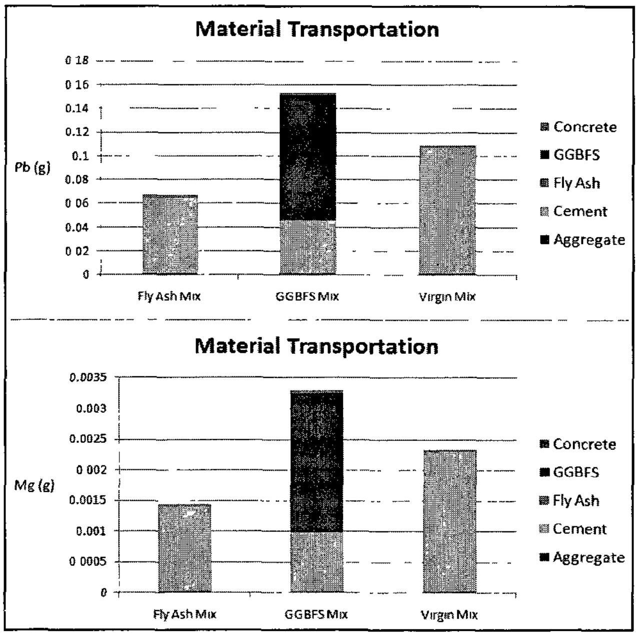


Figure 16 Transportation Lead and Mercury Emission Distribution

Due to the high GGBFS metal emissions from transportation, the mix's emissions exceed the virgin mix, though the CFA case has the lowest emissions, illustrated in

Figure 17, performing better than both of the other mixes.

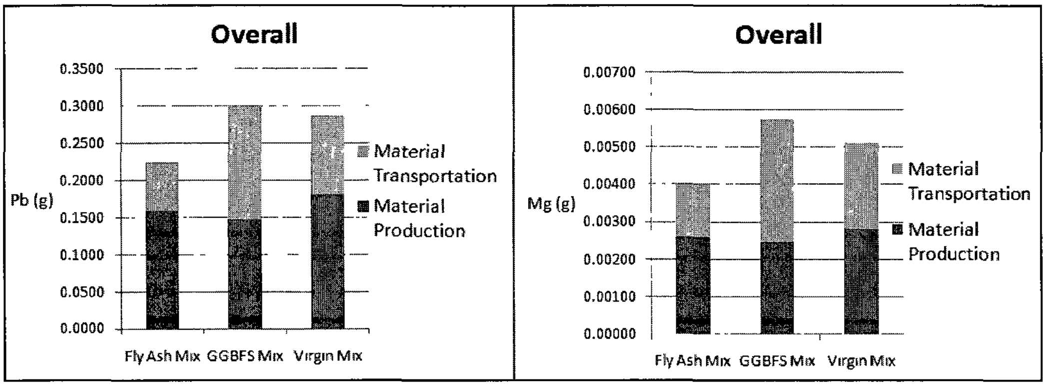


Figure 17 Overall Lead and Mercury Emissions

Human Toxicity Potential

Figure 18 illustrates that both type of HTP emissions are primarily due to concrete and aggregate production, following a similar pattern where the mix's aggregate volume determines the quantity of toxicity leachate potential. The low leachate emissions of industrial byproduct's are not unexpected, as their volumes in the mix are small in proportion to the combination of fine and coarse aggregate. Figure 19 shows the majority of HTP emissions, due to material transportation, come from cement and GGBFS, as these are the two furthest located materials, both over 450 miles. The varying volumes of cement within the mixes explain the differences in emissions for both types of HTP. The addition of GGBFS transportation, the furthest located material (in Maryland), influences the GGBFS mix to have the highest cancerous and non-cancerous HTP, followed by the virgin mix, and then the CFA mix, with the smallest volume of cement, and containing materials from a more local source. This overall distribution is illustrated in Figure 20.

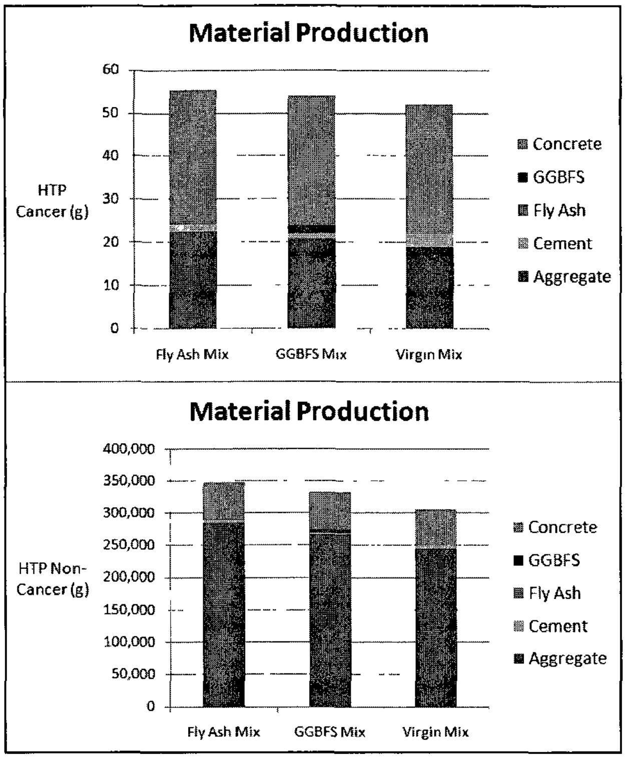


Figure 18 Material Production HTP Distribution

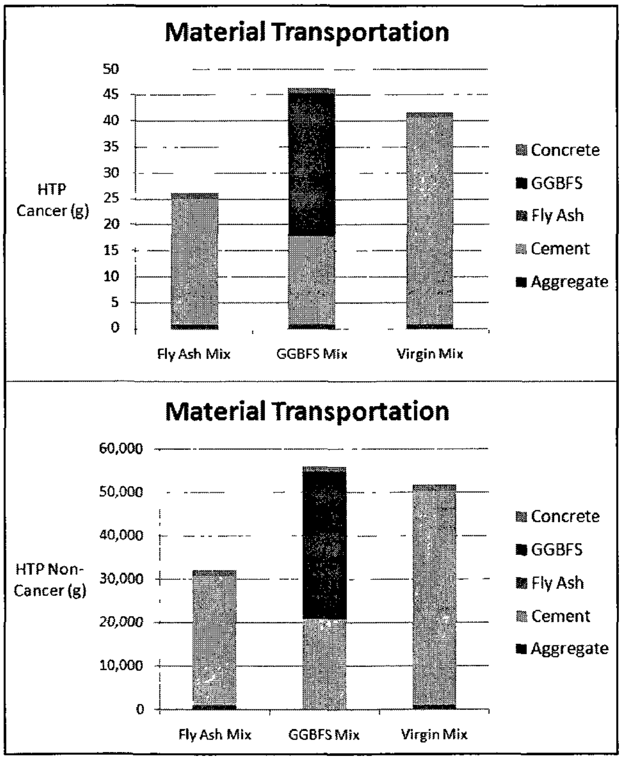


Figure 19 Material Transportation HTP Distribution

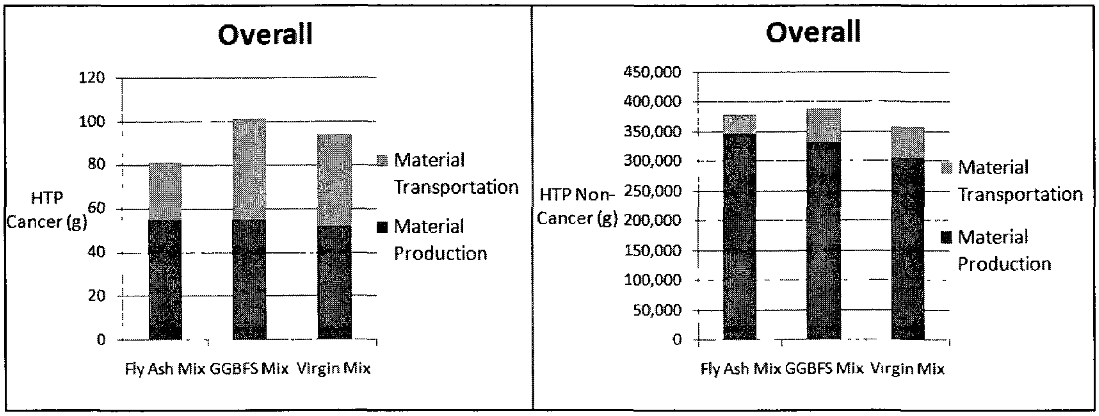


Figure 20 Overall HTP Distribution

Water Consumption

Water is primarily used in the production of concrete and cement, and the transport of cement and GGBFS, similar to the former sub-sections. Figure 21 shows the results that both recycled material mixes have almost equal totals overall, but CFA concrete has the lowest consumption of water between the three mixes.

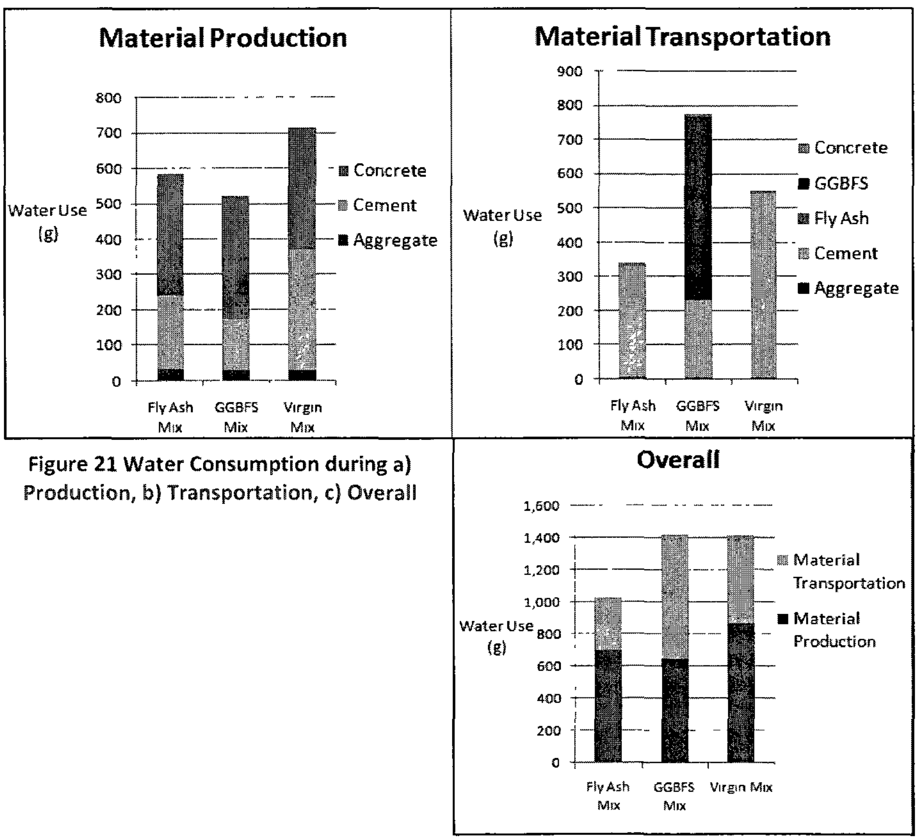


Figure 21 Water Consumption during a) Production, b) Transportation, c) Overall

RCRA Hazardous Waste Generation

Concrete dominates the waste generated by producing materials, differing by the mixes cement volumes, only a small portion of the waste depicted in Figure 22a. Similar to the toxic metal transportation distribution, Figure 22b shows the effects of the longer transportation distances due to the proportional duration of use of petroleum. Seeing as transportation emissions contribute the most for this loading, as shown in Figure 22c, CFA concrete has the lowest quantity of hazardous waste generated, and GGBFS concrete has the highest.

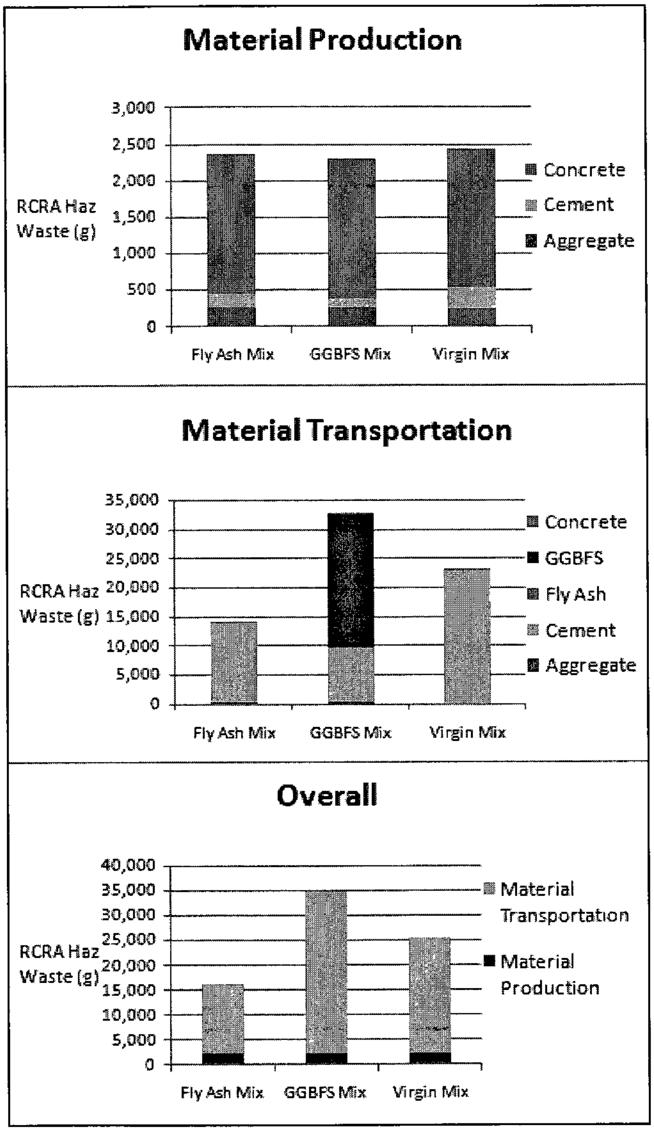


Figure 22 RCRA Waste Generated during Material: a) Production, b) Transportation, c) Overall

Life Cycle Impact Assessment (LCIA)

Classification, Characterization and Valuation

The first step to assessing life-cycle impacts is to classify similar types of environmental loadings into groups with corresponding impact categories and their indicators. The flows of each impact category are described, characterizing the aggregated loadings for each unit process. Finally, the results are valued depending on their potential effects, due to scope (local, regional or global) or priority, and are compared to the other cases to assess which would be the most environmentally beneficial.

Scale	Sign. Factor	Impact Category	Endpoint Effects	Indicator Category	Environmental Loadings
GLOBAL	3	Climate Change	Weather patten change	Global Warming Potential	CO_2 Emissions
		Resource Depletion	Low Material/ Fuel Availability	Energy use	Energy Consumption
REGIONAL	2	Photochemical Smog	Dust pollution and Respiratory Problems	Primary Air Pollutants	PM_{10} Emissions NO_x Emissions CO Emissions SO_2 Emissions
		Acidifcation	Biodiversity and Vegitation Damage	Secondary Air Pollutants Toxic Metals	NO_x Emissions Lead Emissions Mercury Emissions
LOCAL	1	Human Health	Increased Mortality and Cancer	Human Toxicity Potential Primary Air Pollutants	HTP (Cancer or Non-Cancer) PM_{10} Emissions SO_2 Emissions
		Terrestrial Toxicity	Biodiversity Damage	Toxic Metals Waste	Lead Emissions Mercury Emissions RCRA Haz Waste Generated
		Water Use	Low Water Availability	Water Use	Water Consumption

Table 19 Environmental Loading Classification, Characterization and Valuation

PaLATE disaggregates its environmental results into emissions from material production and material transportation, including the calculated HTP and GWP impacts, which characterizes the sources of each environmental loading, mentioned in the LCI. Table 19 illustrates the significance of each loading that PaLATE outputs to the user, basing its assumptions on a table found in the CRC Handbook (documented in Appendix F-2), and EPA's LCA 101 [SAIC 2006]. A subjective value (Significance Factor) is given to each loadings, based on the scope of the environmental impact [Degeare 2011]. The rating system is based on the concept that the higher the scale (local, regional, global) or potential priority to the audience of the study (low, medium, high), the higher the significance factor (1,2,3).

Since the scope factor method may not accurately demonstrate the factors considered a priority by the stakeholders and audience, an additional set of factors were created based on a subjective perspective, acknowledging that global warming, human health, and energy consumption were the dominant indicators in relation to material decision-making. Table 20 summarizes the significance factors to be used, resulting in normalized data comparison. The table is ranked by the priority factors and follows the same order when outlined in the discussion sub-section.

Scope	Indicator	Envrionmental Loading	Significance Factor (Due to Scope)	Significance Factor* (Due to Audience Priorities)
Global	GWP	CO_2 Emissions	3	3
Global	Energy Use	Energy Consumption	3	3
Regional	Air Pollutants	NO_x Emissions	2	2
		PM_{10} Emissions	2	2
		CO Emissions	2	2
		SO_2 Emissions	2	2
Regional	Toxic Metals	Pb Emissions	2	2
		Mg Emissions	2	2
Local	HTP	HTP Cancer	1	2
		HTP Non-Cancer	1	2
Local	Waste	RCRA Hazardous Waste Generation	1	1
Local	Water Use	Water Consumption	1	1

Significance Factor (Scope) 3 - Global, 2 - Regional, 1 - Local

Significance Factor (Audience Priority) 3 - High Priority, 2 - Medium Priority, 1 - Low Priority

* [Degeare]

Table 20 Significance Factors for Each Environmental Loading

4.5 LCA Recommendations

Significance Factor (Due to Scope)	Significance Factor (Due to Audience Priorities)	Environmental Loading	Primary Varying Limiting Factors[1]		Overall Emission Ranking (e.i. highest emission is 3) [2]			Value With Weighting Factors (rank * sign factor$_{Scope}$)			Value With Weighting Factors (rank * sign factor$_{Audience}$)		
			Production	Transportation	CFA	GGBFS	Virgin	CFA	GGBFS	Virgin	CFA	GGBFS	Virgin
3	3	GWP	**Cement**	**GGBFS/Cement**	3	1	2	9	3	6	9	3	6
3	3	Energy Use	**Cement**	GGBFS/Cement	3	1	2	9	3	6	9	3	6
2	2	NO_x	**Cement**	GGBFS	3	1	2	6	2	4	6	2	4
2	2	PM_{10}	**Aggregate**	GGBFS/Aggregate	2	3	1	4	6	2	4	6	2
2	2	CO	**Cement**	Cement/Aggregate	2	3	1	4	6	2	4	6	2
2	2	SO_2	**Cement**	Cement/Aggregate	2	3	1	4	6	2	4	6	2
2	2	Pb	**Cement**	GGBFS/Cement	3	1	2	6	2	4	6	2	4
2	2	Mg	**Cement**	**GGBFS/Cement**	3	1	2	6	2	4	6	2	4
1	2	HTP Cancer	**Concrete/Aggregate**	**GGBFS/Cement**	3	1	2	3	1	2	6	2	4
1	2	HTP Non	**Aggregate**	GGBFS/Cement	2	1	3	2	1	3	4	2	6
1	1	RCRA Waste	Aggregate/Cement	**GGBFS/Cement**	3	1	2	3	1	2	3	1	2
1	1	Water Use	**Cement**	GGBFS/Cement	3	2	1	3	2	1	3	2	1
				Total	**32**	**19**	**21**	**59**	**35**	**38**	**64**	**37**	**43**

Significance Factor (Scope) 3 Global 2 Regional 1 Local
Significance Factor (Audience Priority) 3 High Priority 2 Medium Priority 1 Low Priority
[1] Not including concrete because of common functional unit volume and similar process Bold items are primary material influencing emissions
[2] The concrete mix with the lowest emissions gets a 3 etc

Table 21 Weighted Environmental Emission Comparison of Concrete Mix Designs

Table 21gives a summary of how each mix design performed in relation to each environmental loading analyzed, factoring in the effects of varying scopes (global, regional and local) and priority levels. Ranking totals are based on the distribution of emissions between the material production and transportation phase; the larger the number, the more beneficial it would be to the environment, compared with the other case mixes. Regardless of the method of ranking, CFA concrete has the highest total, followed by the virgin mix, which is similar to GGBFS concrete.

Overall, the production of cement was amongst the highest emissions and energy-intensive processes that were analyzed, though the emission quantities are almost identical in each case, between all loadings. Therefore, it can be concluded that if the functional unit defines each case having the same volume of concrete to be produced and transported, then it may not need to be included in the study, to allow the focus to be on the significant differences within the study.

Looking closer, the rankings are separated by phase, and only the overall emission rankings were calculated per case, assuming similar results to Table 21, exemplifying small variations between the three total ranking methods. Table 22 details these results of allocated emission rankings, concluding that both industrial mix cases have lower overall environmental loadings during production than the virgin mix, assuming that no allocation of emissions from the production of industrial materials is incorporated. Although the CFA case dominated the overall ranking, the GGBFS concrete mix during the production phase ranked the best (with the exception of CO and SO_2 emissions), followed by CFA concrete and then the virgin mix.

Environmental Loading	Production Alone Ranking (i.e. Highest Emissions is 3)			Transportation Alone Ranking (i.e. Highest Emissions is 3)			* If GGBFS Effected Transportation
	CFA Mix	GGBFS Mix	Virgin Mix	CFA Mix	GGBFS Mix	Virgin Mix	
GWP	2	3	1	3	1	2	*
Energy Use	1	2	3	3	1	2	*
NO_x	1	2	3	3	1	2	*
PM_{10}	2	3	1	3	1	2	*
CO	2	3	1	2	1	3	*
SO_2	2	3	1	2	1	3	*
Pb	2	3	1	2	3	1	
Mg	2	3	1	2	3	1	
HTP Cancer	2	3	1	3	1	2	*
HTP Non	2	3	1	3	1	2	*
RCRA Waste	2	3	1	3	1	2	*
Water Use	2	3	1	3	1	2	*
	22	**34**	**16**	**32**	**16**	**24**	

Table 22 Allocated Emissions Ranking Between Phases

The more fuel-intensive the process, such as cement and concrete manufacturing and long distance transportation methods, the more energy is consumed and emissions created from fuel combustion. This explains why a common trend in the results follows a distribution of environmental loadings directly proportional to the material's volume, especially for cement and GGBFS. The replacement of cement volume in both byproduct cases reduces a number of air emissions that would have been emitted by a conventional concrete mix design.

Transportation modes (trucks, barge, rail) primarily emit the following air emissions from the fuel combustion within the engine:

- CO_2 Emissions
- PM_{10} Emissions
- SO_2 Emissions
- NO_x Emissions
- CO Emissions (zero for barges)

According to the program's engine assumptions, transport by barge has the highest fuel efficiency, followed by rail and then trucks, but the NO_x emission factors are three times higher for barges than trucks. The overall transportation-related emissions affect approximately half the total emissions for this case study, resulting in significantly lower emissions for local materials (CFA in Boston compared to GGBFS in Maryland),

The leachate potential loadings are based on the productivity and the differences in types of equipment and material used within the study as well as the components that make up the diesel fuel [Horvath 2004]. Most particle emissions are due to the friction between truck wheels and the pavement or from loading and unloading trucks; therefore, will always be produced and included in these studies.

4.6 Conclusions

Overall, this case study showed that transportation is a large limiting factor within a cradle-to-gate analysis LCA; so materials should be kept as local as possible to minimize the resulting emissions. Between both phases, CFA concrete is the most beneficial to the environment, followed by the virgin mix and then the GGBFS mix. When the phases are split up and the transportation phase is ignored, the production phase shows that the GGBFS concrete is the most environmentally beneficial, followed by CFA concrete and then the virgin mix. On the other hand, the transportation phase shows that the CFA mix is the most environmentally beneficial, followed by the virgin mix and then the GGBFS mix due to the proximity of the source to the use. Overall, the LCA process can be very helpful in terms of ranking which material in a specific application should be better environmentally. Therefore, this could be easily be used to guide the prioritization process for harmonizing material specifications in specific states or regions.

4.7 Limitations/Challenges

Since PaLATE is the only roadway LCA used specifically in the U.S [Horvath 2004], it should be used as a basis for analysis, though a LCA using the PaLATE programs is limited by the inputs and output calculation methods and assumptions. The significant inputs analyzed in this study are shown below, including:

- hauling distances and modes of transportation to the project site,
- material specifications and volumes within the mix, and
- equipment specifications and engine efficiencies.

A LCA is based on the transparency of the program, where the more detailed the user inputs, the more accurate the results. Since this program does not include the processing of industrial materials, such as the grinding and granulation of GGBFS, the accuracy of the emissions may be off. Additionally, the program is based on assumptions made over 5 years ago, and would require the user to update the emission factors and efficiency rates periodically to increase accuracy. Since this is based on the general data from the U.S. Department of Commerce, the processes are also general and do not take into account more energy-efficient processes that may be available or used in specific instances. Finally, the general lack of abundant US LCA programs should influence the user to also conduct other procedures to guide their decision-making for prioritizing materials for harmonization, such as TRACI or eco-indicator to include other options such as the end-of-life emissions.

CHAPTER 5.0 - THE RATING SYSTEM

FINAL COMPARATIVE TOOL TO SUMMARIZE

COMPILED RESULTS

5.1 Introduction and Chapter Objective

The two previous chapters depicted data required for analysis in the selection of top priority recycled material specifications considered easiest and most beneficial to harmonize between regions of states. A remaining step for proper analysis is to create a numerical prioritization system to allow for the comparison of summarized significant factors observed between various materials. This may also serve as a decision-making tool to visually assess differences between states' ability and likelihood of conforming to a common set of regional specifications. The highest priority state for a given recycled material could take the opportunity to be an "expert" state and lead the discussion for material specifications to standardize for the region, similar to the current standardization process mentioned in Chapter 1.

Prioritization System Factors

The factors considered when creating the prioritization system are as follows:

- Recycled material requirements covered? in each state's road specifications and environmental regulations
- Recycled material's history of use each state's transportation systems as well as national or international experience in its use.
- Recycled material's source availability in relation to the state considering
- Recycled material's physical performance in comparison to conventional materials
- Recycled material's economic and environmental benefits and emissions

5.2 Prioritization System

Each factor considered is equally distributed in terms of ratings, ranging from negative 10 to positive 10, illustrated in Table 23 to serve as a base of understanding of what the important factors are when choosing a material to consider. A full distribution of the prioritization system is found in Appendix G, including two more point statements for "-5" and "5". This rating system was based on a subjective perspective to create an easy

Question	-10	0	10	State
Question 1				
Are there National Specifications available for the material/application? (AASHTO or ASTM)	No	Under consideration	Yes	
Question 2				
Does the state conform to the National Specification(s)?	No specification	Current Working item	Yes, specification/ special provision	
Question 3				
Does the state have environmental regulations for the material/application?	No	Current Working Item	Yes, BUD* available for material and application	
Question 4				
What is the history of the material/applications use?	Never been done	Limited information on use in projects	Common practice internationally	
Question 5				
What is the history of the material/ applications use in the state?	Never been done	In the research phase of use	Common practice	
Question 6				
What is the availability of the material in the state?	No availability within 1000 miles	Source within 500 miles	Source within 50 miles	
Question 7				
What is the performance of the material/application compared to the conventional?	Performs significantly worse than conventational	Performs similar to conventional	Performs significantly better than conventional	
Question 8				
Is the application at risk of leaching?	Yes, unencapsulated application - leaching is an issue	Application is above drainage layer - leachate negligable	No, encapsulated application	
Question 9				
What are the environmental effects compared to the conventional?	Significant carcinogenic human toxicity potential	Some negative effects but non-carcinogenic	Less environmental effects than conventional	
Question 10				
What are the economic effects compared to the conventional?	Material significantly costs more than conventional	Material costs similarly compared to conventional	Material sgnificantly costs less than conventional	
* BUD - Beneficial Use Determination			Total	

Table 23 Recycled Material Prioritization System Distributed by Regional State

visual portrayal of the distribution of differences between participating states, allowing a maximum of 100 points per state. The questions used were taken from the factors considered when creating the priority list in Chapter 3 as well as those considered from the AASHTO standardization methods, described in Chapter 1.

5.3 Case Study: CFA and GGBFS in Concrete

Using the prioritization system described on the previous page, a test case study was conducted to demonstrate a general approach to rating and therefore ranking top industrial byproducts under consideration for standard harmonization. Continuing with the harmonization efforts with the Mid-Atlantic States example, CFA and GGBFS as SCMs in concrete road projects were both compared using the prioritization system to test its effectiveness. To simplify this example, only Pennsylvania (PA) and DC are analyzed in hope to exemplify different ratings occurring between neighboring states. The majority of the points should be similar as some factors are general to the materials use, though the small differences between states will ultimately show one product more beneficial over the other. The next sub-section discusses the assumptions made for each rating given per question, shown in Table 5.2 at the end of the data reported below. The completed system is shown in Appendix G.

PA and DC's Use of CFA and GGBFS in Concrete

Both states conform to the national standards that regulate CFA and GGBFS in cement concrete and blended cements, valuing Question 1 as "10" for all cases. Each state's material specifications slightly differ from the national standards mentioned in Chapter 3; the maximum LOI percentage allowed for CFA and the grade of slag allowed both vary. Since there is only one difference in its CFA requirements in PA and DC, the values given for both states are extrapolated to a "9" for Question 2, assuming a rating of

"5" with "some differences" in the specifications is roughly equivalent to five differences within the standard requirements. PA completely conforms to the national standard for GGBFS concrete, though DC differs in its grades of slag allowed, giving "10" points to PA and "9" to DC.

Question 3 discusses each state's environmental regulations; since DC lacks environmental regulations for both materials, it receives values of "0". On the other hand, PA has a BUD process for CFA used in concrete and case-specific regulations for GGBFS in concrete, showing a variation in the state's experience with recycled materials. Question 3 for PA values CFA concrete as a "10" but only an "8" for GGBFS concrete because it is regulated but does not have a BUD program in place.

Question 4 refers to the general history of the material's use, leading to identical priorities between the states due to the general topic of the materials characteristics. Since both materials and applications are common practice nationally and internationally, both are valued at a "10". This differs from Question 5 specifying the experience of the state's use with each material considered; both materials extended history of use values each case at a "10".

Question 6 requires distance calculations from the most local recycled materials source location to either one regionally representative case study project site or to individual state test projects, ranging the from less than 50 miles to over 1000 miles to the material source. If the prior option is chosen, materials are compared with that location alone, varying the material haul distance. Due to this, project site locations were assumed using central PA (Lewistown) and DC.

Using CFA and GGBFS sources listed by the Naval Facilities Engineering Service Center (NFESC) and the Slag Cement Association ["Partial List of Available Fly

Ash and GGBFS"], assumed source locations were Master Builders Inc., where their ProAsh station is produced in Raleigh, NC and Lafarge at Sparrows point in Edgemere MD, granulating the slag on site. A summary table of locations and ratings valued for each material per state, shown in Table 24.

Question 7 asks about the physical performance of each industrial by-product within a highway application compared to conventional virgin materials. Since both CFA and GGBFS have been shown to perform better than conventional concrete without being excessively better and CFA is usually required for bridge decks due to its superior performance, [Hall 2010], the rating was valued as a "5" across the board.

	Location Details	Distance to Project Site in DC & Rating	Distance to Project Site in PA & Rating
Project Site in DC	Washington DC	-	-
Project Site in PA	Lewistown, PA	-	-
Coal Fly Ash Source	**Master Builders Inc. – Carolina Power and Light – Progress Energy Inc.** 160 Rush Street, Raleigh NC	264 miles Mileage < 500 Rate = 0	437 miles Mileage < 500 Rate = 0
Ground Granulated Blast Furnace Slag Source	**Lefarge Cement – Sparrows Point Granulation Plant** 2001 Wharf Road, Edgemere MD	46 miles Mileage < 50 Rate = 10	147 miles Mileage < 250 Rate = 5

Table 24 Case Study's Assumed Distances from a Representative Location in Each Considered

Questions 8 and 9 refer to the environmental impacts from the materials use in highway applications; question 8 requires knowing the materials' leachability potential compared to conventional materials while question 9 compares the overall impacts to conventional materials, including carcinogenic potential, GWP, etc. Since it has been shown that CFA is unlikely to reach groundwater [Churchill et al 1999], it was given a rating of "0" while the leachate potential for GGBFS concrete, similar to conventional materials, rated a "5". If only the material production emission results are assessed, as reported in Chapter 4, CFA concrete showed the least environmental effects, followed by GGBFS and then conventional materials, regardless of the state. Therefore, CFA is rated at a "10" overall, while GGBFS is valued at an "8", extrapolating the results.

Finally, question 10 compares the economic differences between the recycled and the conventional material, varying by source location, which significantly influences a cost difference from state to state. During the working meeting in Maryland [RMRC 2010] discussed in Chapter 3, a representative from PA mentioned CFA as more economical than conventional cement, rating at a "5", since it wasn't significantly cheaper. GGBFS was valued at a "-5" because of increases in costs due to additional asphalt required to handle GGBFS's absorbent characteristics.

Analysis and Conclusion of Prioritization System Example

Various observations were made from this case study to help compare CFA and GGBFS concrete within the Mid-Atlantic State's highway projects. Between all questions, CFA and GGBFS both outranked each other three of the ten questions, tying in the remaining four, illustrating an even distribution between both materials. This is illustrated on the next page in Table 25. Comparing the two states, PA rated better than DC for one question with CFA and two questions with GGBFS, tying with DC for 9 questions using CFA and seven questions using GGBFS. Overall, PA's use of CFA and GGBFS in concrete had the highest rating, showing that it would be a better state for harmonization than DC, or possibly a state to frontier the application among the region.

						CFA - Concrete		GGBFS - Concrete	
Question	-10	-5	0	5	10	PA	DC	PA	DC
Question 1						10	10	10	10
Are there National Specifications available for the material/application? (AASHTO or ASTM)	No	*Research being* done	*Under* consideration	*Currently* working item	Yes				
Question 2						9	9	10	9
Does the state conform to the *National Specification(s)?*	No specification	No specification, *but would*	Current *Working item*	Yes, some *differences*	Yes, specification/ *special provision*				
Question 3						10	0	8	0
Does the state have environmental regulations for the material/application?	No	Under consideration	Current Working Item	Yes, regulated on a case-by-case basis	Yes, BUD* available for material and application				
Question 4						10	10	10	10
What is the history of the material/applications use?	Never been done	In the research phase of use	Limited information on use in projects	Fairly well known nationally	Common practice internationally				
Question 5						10	10	10	10
What is the history of the material/ applications use in the state?	Never been done	No but would consider	In the research phase of use	Small number of projects done	Common practice				
Question 6						0	0	5	10
What is the availability of the material in the state?	No availability within 1000 miles	Source within 1000 miles	Source within 500 miles	Source within 250 miles	Source within 50 miles				
Question 7						5	5	5	5
What is the performance of the material/application compared to the conventional?	Performs significantly worse than conventational	Performs worse than conventional	Performs similar to conventional	Performs better than conventional	Performs significantly better than conventional				
Question 8						0	0	5	5
Is the application at risk of leaching?	Yes, unencapsulated application - leaching is an issue	Yes, unencapsulated application - leachate is minimal	Application is above drainage layer - leachate negligable	Leachate is similar to that of conventional	No, encapsulated application				
Question 9						10	10	8	8
What are the environmental effects compared to the conventional?	Significant Carcinogenic Human Toxicity Potential	Many negative impacts but nothing carcinogenic	Some negative effects but non-carcinogenic	Environmental effects similar to conventional	Less Environmental effects than conventional				
Question 10						5	5	-5	-5
What are the economic effects compared to the conventional?	Material significantly costs more than conventional	Material costs a bit more than conventional	Material costs similarly compared to conventional	Material costs less than conventional	Material significantly costs less than conventional				
					Total	69	59	66	62
					Average	64		64	

* BUD - Beneficial Use Determination

Table 25: Overall Prioritization System Results

Though PA's use of CFA concrete is higher than GGBFS, DC showed opposite results, favoring GGBFS over CFA, mainly due to its local source, under 50 miles away. Coincidently, the averages of each material's rating for these two states were equal, requiring a need to include other states in the analysis to see which exceeds the rest, resulting in a more accurate representation of the distribution of rating values.

This example made assumptions about the location of the project sites and sources used for each specific material. This specific case study should not be used to make any conclusions for the Mid-Atlantic State's potential for harmonization rating values. This is simply a basic view into how a prioritization system could work with the most accurate information. Specific factors should be analyzed further to determine which has priority when choosing material specifications to adopt for regional highway projects.

5.4 Prioritization System Recommendations and Limitations

A general rating system was created in this chapter to help summarize various significant factors considered when choosing recycled materials for harmonization among regions of states. It is important to view the rating values per state to allow participating state regions to assess slight differences between neighboring states and create better systems for a conformed set of regional specifications. Some variations observed include the state's availability and distance to a material source, cost for transport, experience with handling the material, and any accompanying material specifications and environmental regulations within the state.

Since a number of different variables are analyzed in this prioritization system, it's probable some questions will favor one recycled material, while others favor another.

While the prioritization system is meant to help the analysis, the equal-valued system of factors may not account for what decision-making parties considered the most significant when choosing material specifications for use or harmonization. Additionally, the next version of this system would have to consider how to variably weigh the factors as well as how to extrapolate those values when the condition is not easily defined.

CHAPTER 6.0 - RECOMMENDATION

CONCLUSIONS, LIMITATIONS & FUTURE WORK

6.1 Overview

The "New Approach" harmonization in Europe can be used as model to regionally harmonize recycled material specifications in transportation systems across the US. Similar to the "New Approach," a technical group (RMRC) has researched the selected materials and has recommended the most beneficial standards to enhance trade as well as environmental awareness – something the European harmonization did not focus on. The priority standards are also analyzed by material performance, feasibility, and specification conformity however, this paper suggests the environmental impacts should be included, as well as steps which should be taken to change regulations between participating states – a procedure the European harmonization did not include.

Recycled material specifications vary within regional US transportation systems, adding time and money for altering and testing materials, specific for each state. Harmonization between states can avoid costly mistakes during production and distribution phases by producing one product per region. Increased conversation due to harmonization will allow experienced states to frontier the discussion toward selecting the most beneficial regulations.

This thesis illustrates steps following a "reference method" of harmonization [Stevens 1993] for recycled material specification based on variables mentioned above. The procedure may bring public attention to more efficient product development and quality control processes; it may enforce conformity between public and private sectors, enhancing competitiveness in the marketplace [ansi.org].

The overall procedure recommends a data compilation, state communication and comparison and analysis phase. The compilation phase includes background research on selected recycled materials in various transportation applications, participating states material specification conformity and environmental regulations and the compilation of this data into a number of summarization templates. The communication phase includes contact and a working meeting with the participating states to discuss the compiled documents, explain unanswered questions and continue conversation between the neighboring states and its transportation and environmental departments. The comparison phase takes the proposed recycled materials and applications and conducts life-cycle assessments for each to compare its use in each state with natural materials. All the data obtained from these phases is summarized in a prioritization system that considers each decision-making factors to help rank the top priority recycled materials and applications for harmonization.

6.2 Step-by-Step Recommendation

This section breaks down the general steps to be taken in order to create a list of primary recycled materials and applications that helps simplify the decision-making process when proceeding with a specification harmonization among regions of states in the US.

Step 1: Select Recycled Materials for Investigation

This first step is similar to the current standardization procedure in the US, beginning with a group of technical representatives from the US EPA or the FHWA, creating a list of potential recycled materials for analysis for specification harmonization. This list will be dependent on the region, as material availability and feasibility of use varies over the country.

Step 2: Research General Material Characteristics and Select Related Applications

The next step is to create a matrix of the materials and applications that will be researched given the selected recycled materials. After a background search of the materials characteristics is completed, both physical and chemical, a list of applications per material is compiled. The online database mentioned in Chapter 3, called the "User Guidelines for Byproducts and Secondary Use Materials in Pavement Construction", updated in 2008, provides a general description of various material's origins, material properties, environmental concerns, current recycling practices, national material specifications, market sources and various highway applications. However, research should be conducted throughout each material's source information database(s); for example, the most recent SFS information can be found at the Foundry Industry

Recycling Starts Today website. Additional data is also collected for traditional materials for accurate comparison of the performance in different highway applications.

Step 3: Conduct Regional Survey for History of Use within Each State

In order to get the most recent and accurate information about each state's use of selected recycled materials, a survey is sent out to participating states asking about history and use with the applications under considerations. Similar to one created by Jeff Melton for the Mid-Atlantic States case study [Melton 2009], it asks about the use, quantity, and includes comments for additional information the state may want to include, explaining why a material may not be used.

Step 4: Research Material Case Studies for National and International History of Use

Comparative case study reports using modeling programs should be researched within the participating states and internationally for a wide history spectrum of the proper use of each material and application under consideration. The Transportation Research Board is a good source to find technical reports funded by the EPA and FHWA, increasing the data's accuracy and credibility. Test project reports also exist in some participating states' website databases discussing the materials' performance and environmental impact modeling and assessments; the more local the case study to the participating region, the more valuable the data is for prioritization.

Step 5: Obtain National AASHTO or ASTM Material Specifications and EPA Environmental Regulations for BUDs

The first part of this step requires the search of any available material specification pertaining to each industrial byproduct material. More commonly used materials may have multiple specifications, while lesser used materials, such as SFS, may only have a working item for its specifications or lack one at all. The second part requires research into the EPA website to find any related regulations for the beneficial use of industrial byproduct materials.

Step 6: Research the Participating States' Conformity to National Material Specifications and Environmental Regulations

Each state's road specifications are skimmed and recorded, including requirements mentioned for materials being analyzed. For example, though most Mid-Atlantic States conform to the national standard for CFA, most of the states varied by a percentage to what the standard requires of the maximum LOI.

The data is collected by reviewing each individual state's DOT website for road specifications, special provisions or permits, and searching the state's DEP website for any environmental regulation or program that is used for recycled materials.

Step 7: Compile the Initial Researched Data into Fact Sheets and State-by-State Environmental Regulation Matrix

First, this step helps to summarize the extensive amount of information gathered in the last three steps. As shown in Chapter 3, each Fact Sheet compares and contrasts the use of industrial byproducts in a given applications, assessing material properties, history of use, and performance records with comparison to conventional materials. Second, the Fact Sheet then requires national material specifications and any notation of standards adopted by AASHTO, ASTM or the individual state's own standards. The detailed variations between the states, exemplified in Appendix A, allow for a visual comparison of the differences between each state's material specifications.

Taking the information found on state DEP's website, a summary of the various recycled materials under consideration should be created to document the locations of each regulation and any recycling programs in place, such as the tire recycling program with regulations for disposal for PA. This information is placed into a state-by-state environmental regulations matrix, dividing the state's environmental details, shown in Appendix B. Once all the initial data is organized into Fact Sheets and into the matrix, a list of missing information is created for each state about the use and conformity of specifications.

Step 8: Make Contact with Participating State Representatives

At this point, unanswered questions should be sent to representatives of each state's DOT and DEP. The timeline of this process is completely dependent on the availability of the participants and the complexity of the questions; while some missing information may only require a set of permits to be forwarded, others may need multiple e-mails and the availability of state representatives to fully answer a question. The information received may include economic, environmental and performance records of state projects using recycled materials, or provides a reason for the lack of a materials use, offering additional data to either help or hinder the potential conformity to the material specification.

Step 9: Finalize the Fact Sheets and Environmental Regulation Matrix for Distribution and Review

Using the responses from state communication, update and finalize the compiled documents for review by EPA and FHWA representatives. Once reviews and edits are completed, distribute the documents to each participating state for their comments.

Step 10: Create Preliminary Priority List of Recycled Materials and Applications for Specification Harmonization

Combining the components of all compiled documents, create a list of the materials and applications in order of those most likely to have their specifications harmonized among the states; then, group these into a "Yes", "Maybe" or "No" list. Distribute this list to EPA and FHWA for review and comments. An example of this is shown from the Mid-Atlantic States case study, in Appendix C.

Step 11: Facilitate a Working Meeting in a Regionally Representative State to Discuss Priority Materials

Use this meeting to report the findings on the compiled documents and the final priority list. Discuss each material and application, one at a time, recording the benefits or barriers to its use and the specification harmonization potential. Conclude the meeting with two to three materials in specific applications for further analysis. Complete the meeting notes and distribute this to the participating representatives.

Step 12: Perform Representative Life-Cycle Assessment Comparing Priority Recycled Materials Use to Conventional Materials

Using the final two or three materials and applications chosen from the working meeting, conduct a LCA comparing the recycled materials with natural constituents. The LCA should be done in one or more representative states within the area to gain the most accurate knowledge on environmental effects within the region. Following the example shown in Chapter 4, the effects should be compared and analyzed to conclude which material is the most environmentally beneficial.

Step 13: Complete Prioritization System for Each Material for All Participating States

The final step to forming a priority list of recycled materials and application for specification harmonization is to use the prioritization system created in Chapter 5 (Appendix G) to organize all the information compiled in the last 12 steps. The system compares all factors considered when adopting a material specification in a regional state, establishing which state has more experience with a given material and which materials are the most beneficial in terms of performance, environmental impacts and economic considerations.

6.3 Limitations to the Recommended Procedure

There are a number of limitations throughout the procedure recommended in the last section. First, the survey that is sent out to compile accurate data about the materials current use is only useful if each state answers all the questions accurately. The analyst has no control over the state's availability to communicate or their willingness to collaborate with the group working on the harmonization. Due to this uncertainty, the collection of data may be delayed or missing.

When conducting a working meeting to discuss the compiled documents, it is important to recognize that agreements between various states will take a significant amount of time and effort. For those states that can make the working meeting to discuss the variations in material specifications, it was observed that states are unclear why the adjustments were made. Additionally, most states do not consider neighboring states' specifications or programs when choosing what to conform to, complicating the harmonization process. The example case study showed that most of the meeting time was spent on the material and application that was considered to be the easiest specification to harmonize. This may require then a smaller list of priority materials to discuss; acknowledging that one must be prepared to have an extensive conversation about each item and facilitating the meeting to keep on topic will be of great importance.

Transportation distance from a material source to the job site is a significant limiting factor when conducting the comparative LCA using industrial by-products or virgin materials. For example, had the LCA conducted in Chapter 4 been done in Maryland, where GGBFS is produced, easily available, and located in a representative state to the regional audience, the results may have supported the conclusion of GGBFS as the better choice to start harmonization with for the Mid-Atlantic States. Since the

GGBFS used in the LCA case study was located the furthest from the job site in NH, (second being concrete), it was not surprising that the GGBFS concrete mix's environmental emissions exceeded both the CFA and virgin mix cases.

The transportation influence exemplifies the concept of keeping the harmonization regional taking into account variables affecting each area and conducting LCAs in representative states for each region, and not just site-specific projects. If the Mid-Atlantic State representatives consider these recommendations and focus their efforts on CFA and GGBFS in concrete, the next step would be to conduct additional research on the nearest source of CFA (if Boston is not the closest) and repeat the LCA process to compare results. Assuming that CFA will require a longer traveling distance, it would not be surprising if GGBFS concrete is the controlling mix for the Mid-Atlantic States where the slag is abundant.

Additionally, conducting a LCA for step 12 should not be taken as the most accurate reflection of the exact environmental effects for each neighboring state; rather, this can be used to establish a recommendation, but not a concrete conclusion [Stripple 2001]. Similarly, when comparing two materials with different applications using test sections in different locations, constantly changing variables must be taken into consideration, such as the sites' soil composition and terrain, climate, or traffic flows of different compositions of materials being compared.

The use of PaLATE is limited because it excludes the processing phase of any recycled material, which ultimately may favor the recycled material over the conventional [Bringezu 1993]. For the case study LCA in Chapter 4, the GGBFS grinding and granulation process was not included in the analysis, therefore removing a very energy intensive process that may have had significant emissions to outweigh its use to conventional materials. Additionally, the program is not regularly updated, which poses a challenge to accurately model and assess materials in highway applications using the most current techniques and equipment [Hendrickson et al 2006]; this could lead to missing or inaccurate data, either under or over estimating the true environmental loading. Finally, PaLATE is the only LCA pavement program in the US; without the availability of other programs, which would allow verification, there remains some uncertainty in the program's accuracy. The use of European methods (TRACI or eco-indicator) could be another option, though they present limitations as they do not accurately reflect the US transportation system.

Lastly, the prioritization system mentioned in step 13 is only a general attempt at summarizing the data collected over the entire procedure; it does not precisely implicate the true significance of each factor considered. The system should be updated to reflect each factor's actual significance and a similar rating system should then be utilized.

Overall Limitations to Specification Harmonization

One of the biggest challenges for harmonization of any specifications is that it is impossible to control the actions of a large number of people with varying perspectives and differing political agendas from state-to-state. While the European harmonization procedure gave the US a great opportunity to learn from their mistakes, harmonization has never successfully been accomplished in the US. There are substantial obstacles to EPA's and FHWA endeavors for establishing common specifications between regions. Additionally, states hesitate to try new materials for fear of failure, and there is still limited data on the environmental impacts of using these materials. As Warren Buffet, one of the most successful investors in America said: "It takes 20 years to build a reputation and five minutes to ruin it. If you think about that, you'll do things differently."

Consistent with this line of thinking, states are more concerned with the political and economical consequences if a project fails over the potential benefit of learning what doesn't work.

6.4 Future Work

The main challenges to specification harmonization are providing sufficient incentive for states to collaborate with one another, and for potential contactors and industry representatives to come to common agreements. Similar to the WASCON conferences mentioned in Chapter 1, research institutes, state representatives and industry should all be in discussion to begin harmonization with processes such as material extraction and production.

Between 2010 and 2015, $375 billion dollars is being dedicated to highways [AASHTO 2010]. Economic incentive could guide the states to harmonization through the AASHTO Top Priority for 2010, [AASHTO 2010] requiring Congress to present priority policies and funding for transportation programs every six years, thus integrating transportation planning and environmental regulations.

Challenges for the future include finding ways to balance trade and environmental goals, and to monitor and implement policies. The US must recognize the interdependence of the environment and of human actions to achieve environmental goals and manage national quality standards. Following West Virginia's recycled material database, regional states should collaborate to make information more accessible to state transportation and environmental representatives, as well as contractors and industry personnel; this process may result in higher use of industrial byproducts and help researchers when searching for material sources for comparison.

Finally, European harmonization could benefit material product standards and industry but was unable to also harmonize the environmental regulations of use. While this paper included environmental factors for decision-making, such as comparing state BUD programs, future research to harmonize US environmental regulations would be significantly beneficial, especially regionally in areas with similar conditions.

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Appendix A: Material/Application Fact Sheets

BOTTOM ASH

Application: Asphalt Concrete Fine Aggregate (HMA and CMA)

Advantages	Disadvantages
Base - Porous and popcorn shaped particles	Not as durable as conventional aggregate
Been used in asphalt pavement since 1970's	Must be used only on secondary roads
Wearing surface –increase strength & durability	Issues with pyrite: Unstable and weathers
Less potential of leaching metals because of larger particles and encapsulated application	Wearing course - Need more asphalt - porous

Standard Specifications

None to be found mentioning bottom ash but should follow the same specifications for fine aggregate

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	No	-	Never requested use for
District of Columbia	No	-	Not mentioned (Fine aggregate for bituminous concrete - 803.03)
Pennsylvania	No	-	No mention of bottom ash (other than anti-skid) (Fine aggregate 703.1)
Maryland	No	-	Not considered
New Jersey	No	-	Industry had not asked to pursue use
New York	No	-	No need or application for use in projects
Virginia	No	-	-
West Virginia	No	-	They allowed use but then stopped for fear of leaching

Recommendation/Comments

None of the states allow the use of bottom ash in this application so this material/application should not be harmonized.

BOTTOM ASH

Application: Aggregate in Granular Base

Advantages	Disadvantages
Used as granular base since early 1970's	Potential to corrode metal
Public and Private	Unencapsulated – potential to leach metals
Free-draining material – porous	Very fine – may need to blend
Stiffer and angular – distributes load better	
More flexible than conventional aggregate	
Not susceptible to frost heave	
Thinner layers – same strength and deformation	

Standard Specifications

None to be found mentioning bottom ash but should follow same specifications for fine and coarse aggregate

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	No	-	Never requested use for
District of Columbia	No	-	Bottom ash not mentioned (aggregate base course - 209)
Pennsylvania	No	-	Bottom ash not mentioned (aggregate – 703)
Maryland	No	-	Not considered
New Jersey	No	-	Industry had not asked to pursue use
New York	No	-	No need or application for use in projects
Virginia	No	-	Bottom ash not mentioned (sub-base and aggregate base material – 208)
West Virginia	No	-	They used to use it but stopped for fear of leaching Bottom ash not mentioned (Aggregate for base or sub-base – 704.6)

Recommendation/Comments

Bottom ash does not seem to be used often for any application, but if used for a base/sub-base, the specifications should follow those for conventional aggregate in a base/sub-base, unless exceptions need to be made.

BOTTOM ASH

Application: Embankment/Fill and Structural Fill

Advantages

Largest use of bottom ash in US
Successfully used nationally and internationally
Free-draining
Not typically susceptible to frost heave or liquefaction
Short-term performance is excellent
Good strength and compressibility
Non-hazardous according to EPA

Disadvantages

Unencapsulated – potential to leach metals
Angular particles more compressible - not a design concern though
Ferrous metals make particles susceptible to rapid chemical degradation

Standard Specifications

ASTM E 2277: Standard Guide for Design and Construction of Coal Ash Structural Fills

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	No	-	Never requested use for
District of Columbia	No	-	(embankment – 204 and 804.02)
Pennsylvania	No	-	No mention of bottom ash (embankment – 206 and aggregate - 703)
Maryland	No	-	Not considered
New Jersey	No	-	Industry had not asked to pursue use
New York	No	-	No need or application for use in projects
Virginia	No	-	They think bottom ash has toxic metals that EPA will not allow in fills. Tried to get EPA (DEQ) to sign off using ash in fill but regs and monitoring was enormous effort
West Virginia	Yes	-	They used to use it but stopped for fear of leaching Used when lightweight fill needed, an exception, not rule Still consider use – must clear with DEP

Recommendation/Comments

Most states have never been asked to use by industry. Those that have considered it (WV and VA) both feared that the toxic metals would leach out of the fill because it is an un-encapsulated application. More stringent leaching testing should be done if this material is allowed in this application. For structural fills, ASTM E 2277 is recommended for use.

BOTTOM ASH

Application: Flowable Fill Aggregate

Advantages	Disadvantages
No advanced processing required	Issue meeting organic content requirement
Generally meets specifications	Potential to leach material into environment though cement may encapsulate the metals
Lightweight – Better on weak subgrades	
Doesn't need specific moisture content	
Water content can be adjusted easily	

Standard Specifications

AASHTO T19: Standard Method of Test for Bulk Density ("Unit Weight") and Voids in Aggregate

State Specific Specifications

PTM No.510: Sulfate Soundness

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	No	-	Never requested use for
District of Columbia	No	-	No mention of bottom ash (Flowable Backfill - 804.07
Pennsylvania	Yes	Course aggregate **220.2(f)**	Source from Bulletin 14 Max loss of 20% in soundness (**PTM No.510**) 100% passing ½ inch and 0-10% passing No.200
Maryland	No	-	Not considered
New Jersey	No	-	Industry had not asked to pursue use
New York	No	-	No need or application for use in projects
Virginia	No	Special Provision **S302G01-0908**	Permitted use Need special provision
West Virginia	Yes	**219**	**AASHTO T19** – Max LOI = 12% 95% passing ¾ inch, 85-100% passing 3/8 inch, 0-25% passing #100 Considering stopping use – potential of leaching Consider use case by case

Recommendation/Comments

Only three states allow the use of it and others have never been asked to pursue its use. Along with specific exceptions, this material should conform to gradation and other specifications for coarse aggregate used in a fill or cement concrete.

BOTTOM ASH

Application: Stabilized Base Aggregate

Advantages	Disadvantages
Partial or full substitution for aggregate in PC (up to 95% - the rest can be fly ash)	May not meet gradation spec – need to blend
Used successfully since 1950's	Angular – higher asphalt demand
Compacted unit weight is lower than conventional	Shrinkage cracks concern
	Unencapsulated – potential to leach metals

Standard Specifications

AASHTO TF28: Guidelines and Guide Specifications for Using Pozzolanic Stabilized Mixture (Base Course or Subbase) and Fly Ash for In-Place Subgrade Soil Modifications

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	No	-	Never requested use for
District of Columbia	No	-	Bottom ash not mentioned (aggregate base course - 209)
Pennsylvania	No	-	Bottom ash not mentioned (aggregate – 703)
Maryland	No	-	Not considered
New Jersey	No	-	Industry had not asked to pursue use
New York	No	-	No need or application for use in projects
Virginia	No	-	Bottom ash not mentioned (sub-base and aggregate base material – 208)
West Virginia	No	-	They used to use it but stopped for fear of leaching Bottom ash not mentioned (Aggregate for base or sub-base – 704.6)

Recommendation/Comments

None of the Mid-Atlantic States allow the use of this material in stabilized base because they have not been asked by the industry. Not sure if the specifications listed above would apply for an aggregate used in stabilized base. If not, then the specifications should be those used for an aggregate in a stabilized base/base/sub-base, with whatever exceptions should be made.

FLY ASH

Application: Flowable Fill (Aggregate and Cementitious Material)

Advantages	Disadvantages
Been used since the 1960's	Unencapsulated material – potential to leach
Can be less expensive than sand if available decrease in excavation costs	Must anchor to lighter weight pipes to prevent floating
Improves long-term strength of fill	Some resistance from contractors to use
Reduced amount of cement required	
Can be placed under freezing conditions	No set proportioning for fly ash in flowable fill

Standard Specifications

AASHTO M295: Coal Fly Ash and Raw or Calcinated Natural Pozzolan for use in Concrete Concrete

State Mentioned Specifications

AASHTO T23: Standard Method of Test for Making and Curing Concrete Test
ASTM D5971: Standard Practice for Sampling Freshly Mixed Controlled Low-
ASTM D483: Standard Test Method for Preparation and Testing of Controlled Low Strength Material (CLSM) Test Cylinders

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	Yes	**Special Provision 208500** Follows 822	Conforms to **AASHTO M295** (C or F) Max LOI = 4% % of substitution is based on strength testing Test by TCLP (EPA SW-846)
District of Columbia	Yes	**804.07** Follows 801.05	Conforms to **AASHTO M295** (F), Mentions **ASTM C31** Do not use calcium accelerators with fly ash
Pennsylvania	Yes	**220.2(b)** Follows 724.2	**AASHTO M295** - Table 1 (F or C), Max LOI = 16% excludes requirements of Table 1A, 2 or 2A – Bulletin 15
Maryland	Yes	**314.02** Follows 902.06.04(b)	Conforms to **AASHTO M295** (C or F) Max Moisture content = 1% - Max LOI = 3% Chemical analysis by EPA EP Toxicity Standards
New Jersey	Yes	**903.09** Follows 903.02.03	**ASTM D5971** – do additional cylinders to make sure strength less than 150psi in 90 days
New York	Yes	**204** Follows 711-10	Conforms to **AASHTO M295** (Class F) Table 2 (except footnote A) Waives LOI requirement
Virginia	Yes	**Special Provision S302G01-0908** Follows 214 and 215	No specific requirement for fineness, LOI, or reactivity. Conforms to **AASHTO M295** (C and F) Design compressive strength according to **ASTM D4832**
West Virginia	Yes	**219** Follows 707.4.1	**AASHTO M295** – Max LOI = 12%

Recommendation/Comments

All states allow the use of fly ash in flowable fill, but the LOI's vary from 3% to no maximum. Recommend harmonizing states to use AASHTO M295 or come up with specification that can be used for flowable fill. The actual volumes being placed by states are quite small, so the market and benefits for using CFA in flowable fill are low. This is a low priority application, unless some states are putting it everywhere, which is doubtful.

FLY ASH

Application: Concrete (Mineral Filler)

Advantages	Disadvantages
Studied use since 1931	Some reported poor performance with fly ash
Hydrophobic, reduces stripping potential	Mix may become tender during hot weather
Properties comparable to limestone dust	Fly ash must be dry
Study – fly ash retards age of hardening	Lack of performance data on fly ash in mineral filler
May be lower cost than other fillers	May result in dust generation – dusty material

Standard Specifications

AASHTO M17: Standard Specification for Mineral Filler for Bituminous Paving Mixtures

AASHTO T37: Standard Method of Test for Sieve Analysis of Mineral Filler for Hot Mix Asphalt (HMA)

State Mentioned Specifications

AASHTO T168: Sampling Bituminous Paving Mixtures

AASHTO T165: Standard Method of Test for Effect of Water on Compressive Strength of Compacted Bituminous Mixtures

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	No	-	Never been asked by industry
District of Columbia	Yes	**803.05**	Conforms to **AASHTO M17** "Fly ash shall not be used for mineral filler unless approved by Chief Engineer" Moisture content < 0.5% - 100% passing No.30, 95-100% passing No.50, 70-100% passing No.200
Pennsylvania	Yes	**703.1(c)1**	Free of clay - 100% passing No.30, 95-100% passing No.50, 90-100% passing No.100, 70-100% passing N.200
Maryland	Yes	**Table 901B**	Conforms to **AASHTO M17** – Max LOI = 12%
New Jersey	Yes	**901.05.03**	Conforms to **AASHTO T37** "Ensure the a HMA mixture containing the filler retains 70% of its initial strength after immersion cycle of 14 days when prepared according to **AASHTO T168** and tested according to **AASHTO T165**" 95-100% passing No.50, 70-100% passing No.200
New York	No	**703-08**	Conforms to **AASHTO M17** – free from agglomerations
Virginia	No	**201**	Conforms to **AASHTO M17** Testing conforms to **AASHTO T37** *Not used because too fine – concern of material degradation during compaction (Illinois DOT)
West Virginia	Yes	**702.4**	Spec doesn't include fly ash but allowed if requirements met. Conforms to **AASHTO M17** Free from harmful organic impurities Before asphalt plants starting using bag houses, fly ash was sometimes used as mineral filler. Bag houses provided a way for the contractors to collect the dust from their aggregates and feed it back into the mix. Fly ash was no longer needed. The asphalt plant bag house usually provides all of the dust needed for HMA production.

Recommendation/Comments

Five of the states allow the use of fly ash in mineral filler. Of those, only three agree on the gradation requirements. Most agree that the fly ash should be free from organic impurities. Maryland has a requirement for the maximum Loss of Ignition at 12%. This raises questions if there will be issues minimizing the potential absorption of asphalt. Also important to mention there is no standard for the carbon content or LOI for fly ash used in mineral filler. Performance in this application is based on the calcium content and the free or available lime content, which can be used as an aid for anti-stripping. Only 1-2% of lime is required to satisfy anti-stripping, therefore the question seems to be what is the optimum calcium content of the ash for anti-stripping properties without detrimental effects to the mixture. If harmonized, the material should conform to AASHTO M17.

FLY ASH

Application: Cement Concrete SCM

Advantages	Disadvantages
Been used for 60 years – well known	Slower early strength development
May reduce costs and increase durability	Heat of hydration reduced in colder climates
Improved cohesion of paste	Longer setting time
Enhanced workability and strength	More difficult to control air content
Decreased water demand	
Resistance to ASR and shrinkage cracking	
Reduced bleeding and permeability	

Standard Specifications

AASHTO M295: Coal Fly Ash and Raw or Calcinated Natural Pozzolan for use in Concrete

AASHTO C311: Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete

State Mentioned Specifications

AASHTO M240: Standard Specification for Blended Hydraulic Cements

AASHTO T303 Standard Method of Test for Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to ASR

ASTM C441: Test Method for Effectiveness of Pozzolans or Ground Blast Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	Yes	Blended **801**	Conforms to **AASHTO M240** (IP)
		Pozzolan **822**	Conforms to **AASHTO M295** (C or F), Max LOI = 4% Minimum 20% substitute for PC
District of Columbia	Yes	Blended **801.03**	Conforms to **AASHTO M240** (IP)
		Pozzolan **801.05**	Conforms to **AASHTO M295**(C and F) Max LOI = 4%, substitute up to 15%
Pennsylvania	Yes	Blended **704.1(h)3.b**	Conforms to **AASHTO M240** (IP) source from Bulletin 15 Max alkali content = 1.5% Min of 15% substitute ASTM C441 **AASHTO T 303** > 0.40% -min 20% Max of 15% replace PCC – rest fine aggregate
		Pozzolan **724.2**	Conforms to **AASHTO M295** (C,F and N) Max LOI = 6%
Maryland	Yes	Blended **902.04**	Conforms to **AASHTO M240** (PM or IP). Substitute 15-25% by weight.
		Pozzolan **902.06.04(b)**	Conforms to **AASHTO M295** (C or F) Max Moisture content = 1% - Max LOI = 3%
New Jersey	Yes	Blended **903.01**	Conforms to **AASHTO M240** (IP) Max of 25% by weight
		Pozzolan **903.02.03**	Conforms to **AASHTO M295** (C and F) Max LOI = 3% - Use Class F for ASR Note: use at least 15% by weight If **AASHTO T303** >0.4% - use 20%
New York	Yes	Blended **704-03**	Conforms to **AASHTO M240** (IP), < 22% by weight Ternary blend cement – from 15-20% by weight
		Pozzolan **711-10**	Conforms to **AASHTO M295** (F), Max LOI = 4% - Table 2 (except A) doesn't use C or N but open to it
Virginia	Yes	Blended **214** Follows 241 and 217.02	Conforms to **AASHTO M240** (IP)
		Pozzolan **215.02** Follows 241and Special Provision S217BG0-0708	Conforms to **AASHTO M295** (C and F) **AASHTO C441** – max expansion of 0.1% at 56 days Class F – between 20-25% by weight of cementitious material No more than 15% of PC in mixture can be replaced
West Virginia	Yes	Blended **701.3**	Conforms to **AASHTO M240** (IP)
		Pozzolan **707.4**	Conforms to **AASHTO C311** & **AASHTO M295** (C and F) Max LOI = 6%. Retained on No.325 = 34% max

Recommendation/Comments

The main difference between these states is the maximum allowed Loss of Ignition. Unless there is a substantial reason for them being smaller or larger than the national specification, each state should be able to conform to ASTM C618/AASHTO M295, ASTM C311/AASHTO C311 and ASTM C595 with its maximum LOI equal to 5%. If able to conform to this, then 4% should be attempted to derail costs for air-entraining agents.

FLY ASH

Application: Stabilized Base/Stabilized Subgrade

Advantages

Excellent performance and improved strength
Little to no processing required – energy efficient
Used since 1950's (Poz-o-Pac)
Improves soft sub-surface material
Less susceptible to fatigue failure
Increased stiffness –less surface deflection
More economical than traditional base – less maintenance

Disadvantages

Used for low traffic – may not be applicable for highways
Potential for leaching
May be susceptible to cracking
Must gain strength before first freeze-thaw cycle - Need proper sealing to resist skidding

Standard Specifications

ASTM C593: Standard Specification for Fly Ash and Other Pozzolans for Use with Lime for Soil Stabilization

AASHTO TF28: Guidelines and Guide Specifications for Using Pozzolanic Stabilized Mixture (Base Course or Sub-base) and Fly Ash for In-Place Subgrade Soil Modifications

ASTM D5239: Standard Practice for Characterizing fly ash for Use in soil stabilization

AASHTO M295 Coal Fly Ash and Raw or Calcinated Natural Pozzolan for use in Concrete

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	No	-	Never been asked by the industry to use
District of Columbia	Yes	Aggregate Base Course **209.02**	Conforms to **ASTM C593**
Pennsylvania	Yes	Aggregate-cement base course **321** Follows 704.1(h)3.b Plain cement concrete base **301** Follows 724.2	Conforms to **ASTM C593** (IP) Conforms to **ASTM C618** (C,F and N) Max LOI = 6% May substitute portion of Portland cement
Maryland	No	-	*Potential to leach toxins into groundwater* caution when it comes to these materials because the entire state (essentially) drains into the Chesapeake Bay.
New Jersey	Yes	-	Rarely do soil stabilization – haven't used in over 20 years – not considered standard material But is option when use – Spec is job specific
New York	No	-	Not prohibited but has not placed stabilized base in over 20 years
Virginia	Yes	Lime Stabilization **306.02(b)** Follows 241.01(b)	Conforms to **ASTM C593** Transported with < 15% moisture
West Virginia	No	-	

Recommendation/Comments

Though five of the states allow the use of fly ash in stabilized bases, NJ and NY do not typically use stabilized bases in general, therefore, they do not have specification for this application. Maryland has issues with leaching because this is an un-encapsulated application. If conformed, ASTM C593 is recommended.

FLY ASH

Application: Embankment/Fill and Structural Fill

Advantages	Disadvantages
Been used since the 1950's in the US and internationally	Dust control is an issue when delivered outside of the proper moisture range
Low unit weight compared to soil or rock	May be subject to erosion
Good for placement over low bearing strength soils	May become saturated at bottom and lose shear strength
Can be compacted during winter conditions	Potential impacts to groundwater
Good bearing support and low settlement	
May reduce construction time and costs -where bulk quantities or fly ash available	

Standard Specifications

ASTM E 2277: Standard Guide for Design and Construction of Coal Ash Structural Fills

ASTM E1266: Standard Practice for Processing Mixtures of Lime, Fly Ash, and Heavy Metal Wastes in Structural Fills and Other Construction Applications

AASHTO PP59: Standard Practice for Coal Combustion Fly Ash for Embankments

State Mentioned Specifications

AASHTO T103: Standard Method of Test for Soundness of Aggregate by Freezing and Thawing

AASHTO T104: Standard Method of Test for Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate

AASHTO T27: Sieve Analysis of Fine and Course Aggregates

AASHTO T21: Organic Impurities in Fine Aggregates for Concrete

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	Yes	-	No spec for use Only used once in mid-90's – not typical application
District of Columbia	No	-	Doesn't mention fly ash (Embankment-804.02)
Pennsylvania	No	-	Doesn't mention fly ash (embankment 206)
Maryland	No	-	Do not allow use
New Jersey	No	-	Too many engineering constraints about using fly ash for us to consider it as a viable substitute for clean fill which is the cheapest and easiest material to use.
New York	No	-	Embankment - Not prohibited – no specs for its use though AASHTO is working on such a spec NYSDOT partnered with several entities in the past to use Fly Ash on pilot embankment projects. These entities include The Empire State Electric Energy Research Corporation, New York State Police, New York State Electric and Gas, and the New York State Department of Environmental Conversation. The projects that were attempted, were either canceled or shelved because of several issues such as site selection difficulties, local governmental opposition, and budgetary reasons
Virginia	Yes	Fine aggregate **202**	**AASHTO T27** (gradation), **AASHTO T103** and **T104 (**Soundness) and **AASHTO T21** (organic impurities)
West Virginia	No	-	Allowed the use of fly ash for a number of years in select embankments but recently were persuaded by several environmental leaching claims to stop and take a careful look at this. They will now only allow it with a special provision on a project basis

Recommendation/Comments

Though two states allow the use of fly ash in embankments, Delaware does not use this as a common application. Since this is an un-encapsulated application, there is a potential for leaching contaminants into the groundwater. This is not a typical use for fly ash and is commonly used on a case by case basis. None of the states use the recommended specification, so this would be a material/application on the low priority list. If harmonized, AASHTO PP59 would be recommended as the priority specification for this application.

FOUNDRY SAND

Application: Concrete Aggregate (HMA)

Advantages	Disadvantages
Stability is higher than conventional	Angular shape – higher cement and water demand
Higher moisture resistance	Poorly graded – too fine – must blend
Very uniform	Hydrophilic – results in stripping of pavement
Good durability and resistance to weathering	Potential of discharging phenol from stockpiles
	Lack of standard methods to test suitability

Standard Specifications

Work Item: **ASTM WK24622**: New Specification for the use of Foundry Sand in Bituminous Mixtures

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	No	-	Never been approached by industry to use
District of Columbia	No		No foundry
Pennsylvania	Yes	**703.1(a)**	Following Table A, from source in Bulletin 14
Maryland	No	-	No request from producer
New Jersey	No	-	Industry has not asked to pursue use
New York	No	-	No appreciable sources of foundry sand to warrant pursing use on projects
Virginia	No	-	They do not have large steel operations in Virginia, so the material is not available in large, consistent supplies.
West Virginia	No	-	They don't enough of a supply to make a specification

Recommendation/Comments

The new specification for foundry sand, ASTM WK24622 should be used for foundry sand used in asphalt concrete. Most states did not mention foundry sand, from either never being asked to use the material, or the fact that foundry sand is not readily available to them for lack of large steel operations.

FOUNDRY SAND

Application: Embankment/Fill and Structural Fill

Advantages

Performance and strength comparable to natural
Groundwater contamination below EPA drinking water limits
More consistent and uniform than natural
Leachate comparable to conventional sand
Leachate Nonhazardous
Without fines – low to no frost susceptibility

Disadvantages

Dust issues – surface must be watered often
Unencapsulated - Potential to leach metals

Standard Specifications

Working Item AASHTO: Standard Practice for Foundry Sand for Structural Fill and Embankments

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	No	-	Never been approached by industry to use
District of Columbia	No		No foundry
Pennsylvania	Yes	**General Permit WMGR019 C(9)(a)**	Used to level area or bring to grade where construction is complete or will commence within 3 months after placement of foundry sand Must meet limits in Table 1of Condition C(2)(a)
Maryland	No	-	No request from producer
New Jersey	No	-	Industry has not asked to pursue use
New York	No	-	No appreciable sources of foundry sand to warrant pursing use on projects
Virginia	No	-	They do not have large steel operations in Virginia, so the material is not available in large, consistent supplies.
West Virginia	No	-	They don't enough of a supply to make a specification

Recommendation/Comments

There is a pending specification for foundry sand used in embankments or structural fill. Most states did not mention foundry sand, from either never being asked to use the material, or the fact that foundry sand is not readily available to them for lack of large steel operations.

FOUNDRY SAND

Application: Flowable Fill Aggregate

Advantages

More uniform size of sand particles
Good flow properties
Noncorrosive – low enough pH
Higher cementitious content

Disadvantages

Potential to leach metals
Finer than conventional – must blend
May contain porous carbon
Lack information on gradation requirements

Standard Specifications

No specification found for foundry sand in flowable fill

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	No	-	Never been approached by industry to use
District of Columbia	No		No foundry
Pennsylvania	Yes	**220.2(e)** Also **703.1**	Max loss of 20% in soundness (**PTM No.510**) Source from Bulletin 14
Maryland	No	-	No request from producer
New Jersey	No	-	Industry has not asked to pursue use
New York	No	-	No appreciable sources of foundry sand to warrant pursing use on projects
Virginia	No	-	They do not have large steel operations in Virginia, so the material is not available in large, consistent supplies.
West Virginia	No	-	They don't enough of a supply to make a specification

Recommendation/Comments

No formal specification for the use of foundry sand in flowable fill. Most states did not mention foundry sand, from either never being asked to use the material, or the fact that foundry sand is not readily available to them for lack of large steel operations. If used, would recommend specifications for fine aggregate, with whatever exceptions must be made for foundry sands.

FOUNDRY SAND

Application: Portland Cement Concrete Fine Aggregate

Advantages	Disadvantages
Performance is comparable to natural sand	Not enough case studies documented
Replaces part of fine aggregates	Finer than conventional – must blend
	Dust issues – higher water demand
	May change concrete color to a grayish/black tint

Standard Specifications

No specification found for foundry sand used as a cement concrete aggregate

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	No	-	Never been approached by industry to use
District of Columbia	No	-	No foundry
Pennsylvania	No	-	Do not allow it
Maryland	No	-	No request from producer
New Jersey	No	-	Industry has not asked to pursue use
New York	No	-	No appreciable sources of foundry sand to warrant pursing use on projects
Virginia	No	-	They do not have large steel operations in Virginia, so the material is not available in large, consistent supplies.
West Virginia	No	-	They don't enough of a supply to make a specification

Recommendation/Comments

No specific specification for foundry sand as cement concrete fine aggregate. Most states did not mention foundry sand, from either never being asked to use the material, or the fact that foundry sand is not readily available to them for lack of large steel operations. If used, would recommend using specifications for a fine aggregate used for cement concrete, with the exceptions for using foundry sand. Low on the priority list since no state allows its use.

SCRAP ASPHALT SHINGLES

Application: Asphalt Concrete Aggregate and Binder

(HMA and Asphalt Cement Codifier)

Advantages	Disadvantages
May contain more than 30% asphalt	Concerns with Asbestos
Improved rutting	Lower Fatigue resistance – stiffer
As aggregate – reduces thickness of layer – requires less compaction – controls dust	Felt-back shingles – may deform in cold temperatures before thermal cracking
As cold-patch mix – compares to high performance mix	Tear-off may still contain nails
Tear-off easy to shred	Shingles may solidify while stockpiled
Processing shingles less expensive than asphalt concrete	Producers report difficulties producing consistent mix – may delay project

Standard Specifications

AASHTO MP15:	Standard Specification for Use of Reclaimed Asphalt Shingles as an Additive in HMA
AASHTO PP53:	Standard Practice for Design Considerations When Using Reclaimed Asphalt Shingles in HMA

State Mentioned Specifications

AASHTO M320:	Standard Specification for Performance-Graded Asphalt Binder
AASHTO M323:	Standard Spec for Superpave Volumetric Mix Design
ASTM D242:	Standard Spec for Mineral Filler for Bituminous Paving Material
ASTM D692:	Standard Spec for Course Aggregate for Bituminous Paving Material
ASTM D693:	Standard Spec for Crushed Aggregate for Macadam Pavements
ASTM D979:	Standard Spec for Sampling Bituminous Paving Mixtures
ASTM D1073:	Standard Spec for Fine Aggregate for Bituminous Paving Material

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	Yes	Special provision **4016xx** Tabs only	Tabs must be free of foreign material and moisture Keep fiberglass-backed and organic felt-backed separate 100% passing 2in sieve – 5% max Never had requested use of tear off
District of Columbia	No	-	Contractor shall not use shingles (bituminous concrete mixtures - 818)
Pennsylvania	Yes	**General Permit #WMGM039 Appendix A** Tear off and tabs	Used for HMA, Cold Mix, sub-base and dust control May not contain asbestos and construction debris Stored by 25 Pa/ Code 299 Subchapter A (standards for storage of residual wastes) Conforms to: **ASTM D242, ASTM D692, ASTM D693, ASTM D979, ASTM D1073, AASHTO MP15** Allows standard max (assume 5%?)
Maryland	Yes	**904.02 MSMT 412** Tabs only	Conforms to **AASHTO M320**, Table 1, Max of 5% tabs Conforms to **MSMT 412** and **AASHTO M323** Do not use for gap-graded mixes
New Jersey	Yes	**901.05.06 902.02.02-1** Tabs only	Max of 5% tabs, 100% passing 3/4inch sieve Petroleum asphalt: 30-40%, Fibers at 10% max Mineral Matter between 50-65% NJ Dept. of Env. Protection do not allow tear off shingles because of asbestos concerns
New York	No	-	Do not use tear-off because cost to clean out wood and nails outweighs benefits of using in HMA – producers reported difficulties in producing consistent mix They do not use but would be open to a pilot/test section
Virginia	Yes	Special Provision **S211JG0-0609** Tear off and tabs Follows 211.02	Tear-off shall be free of paper, wood, nails or metal 100% passing ½ inch sieve – "Contractor shall furnish test results of RAS sample analysis for Polarized Light Microscopy (PLM) on the tear-off shingles which certify the material to be used is free of asbestos." Test at a 1 per 100 ton rate Conforms to **AASHTO M320**
West Virginia	No	-	They don't have enough of a supply to make a spec

Recommendation/Comments

Shingles were found to be used mainly as a special provision by five of the states, where 40% allowed both tear off and tabs and the remaining 60% only allowed tabs. This was mainly because of the cost to clean them and concerns of asbestos. If allowed use, 5% max should be used according to the main specifications AASHTO MP15, AASHTO PP53, and AASHTO M320.

SCRAP TIRES

Application: Asphalt Concrete

Advantages	Disadvantages
Reflective cracking reduced	Performance varies widely
Reduced thickness of layer	Crumb rubber costs 1.5-2 times more than asphalt
Fatigue life improved	Varying viscosities – challenge for storage and pumping
	Limited amount of data on emissions and environmental effect

Standard Specifications

ASTM D6114: Standard Specification for Asphalt-Rubber Binder

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	Yes	Surface Treatment **Special Provision 4015xx**	Vulcanized rubber from ambient temp – pneumatic tires Must meet gradation – 100% passing 2mm, 90-100% passing 1.18mm, 35-75% passing 0.6mm, and 0-20% 0.18mm – length of panel less than 1/8th inch
		HMA binder **Special Provision 401682**	Conforms to **ASTM D6114** Type II Vulcanized rubber from ambient grinding processes only 1.10 < Specific gravity < 1.20 Up to 4% calcium carbonate or talc (by weight of rubber) Have used in one project and working on another
District of Columbia	No	-	Only used in sidewalks. Works well
Pennsylvania	Yes	**409 – Special Provision 4481A And General Permit WMGR038**	Conforms to **ASTM D5461**-02 (except 50gram sample size and max allowable loss of 7.65%) Do not exceed 0.5% of total mix weight And grading requirements shown on provision
Maryland	No	-	Does not use. Never given the opportunity
New Jersey	Yes	**Section 40x**	Gs = 1.15 ± .05 and free of wire and other contaminants Must contain < 0.5% fabric, moisture content < 0.75% May add up to 4% calcium carbonate by weight of rubber 100% passing No.8, 65-100% passing No.16, 20-100% passing No.300, 0-45% passing No.50 and 0-5% passing No.200 (**AASHTO T27** using min 50 gram sample)
New York	Yes	-	Limited amount of asphalt binder
Virginia	Yes	-	Case specific
West Virginia	No	-	-

Recommendation/Comments

Only one state has scrap tire as part of their specifications. Two states treat this application as a special provision or require a permit. Though NY and VA allow the use of tires in asphalt concrete, NY is limited on the amount of asphalt binder available and VA allows this on a case by case basis. If this material was to be harmonized, ASTM D6114 would be recommended.

SCRAP TIRES

Application: Embankment/Fill

Advantages	Disadvantages
Used by 15 states – over 70 successful projects	Tires are combustible
Reduced unit weight – good on low bearing capacity soils	Long-term settlement
	Problems with compaction
Good thermal performance in cold weather	Little information on quality control
Good drainage – similar to granular soils	
Very economical compared to borrow	
Reduces large volume of dumped tires	

Standard Specifications

ASTM D6270: Standard Practice for Use of Scrap Tires in Civil Engineering Applications

State Mentioned Specifications

AASHTO T27: Standard Method for Sieve Analysis of Fine and Course Aggregate

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	Yes	**Special Provisions 202xxx**	Conforms to **ASTM D6270** and grading with **AASHTO T27** – Min sample size is 30 pounds Must be free of contamination, debris, or tire fire remains Produced by hammer mill not allowed They don't know why ^ "The STE shall have less than 1% (by weight) of metal fragments that are not at least partially encased in rubber. Metal fragments that are partially encased in rubber shall protrude no more than 1 in. from the cut edge of the STE on 75% of the pieces (by weight) and no more than 2 in. on 90% of the pieces (by weight)."
District of Columbia	No	-	Do not use
Pennsylvania	No	-	Pending for use
Maryland	No	-	Do not use
New Jersey	No	-	They did one job. It was successful. But the only reason that tires were used is because they forced the contractor to use them. If they had made it optional, he would not have used tires in the embankment. Contractors think that the tires are more trouble than they're worth. Don't want to pay premiums for product that's problematic
New York	Yes	Sampling and Testing **GCP -19 Rev #6** Placement **203.0397 XX M** Delivery **203.0396nnXX M** Guidelines **GEM-20**	2003-2008- NYDOT used equivalent of 5.6 million tires in embankments and engineered fills design Supply of Tire Derived Aggregate (TDA) exhausted and use of TDA suspended "Total weight of shreds with a maximum dimension greater than 12in. (300mm)and less than 16in.(400mm) shall be less than 10% by weight of total sample. Maximum dimension in any direction shall not exceed 16in.(400mm)" 100% passing 16in, 90-100% passing 12 in, 75-100% , 0-25% 1.5 inch, 0-1% passing No.4
Virginia	No	-	Permitted by select use special provisions
West Virginia	No	-	Not allowed because hasn't been presented for use

Recommendation/Comments

Most specifications for tire use in embankments are special provisions, but only allowed in three of the Mid-Atlantic States. Other states have never been presented with this application or are seen as more trouble than they are worth. NY has a Tire shred initiative working to use tires to replace aggregate needed for embankments. If used, they should conform to the specifications of ASTM D6270.

STEEL SLAG

Application: Asphalt Concrete Aggregate

Advantages	Disadvantages
Used internationally – successfully used	Can expand by 10% in humid climates
Good frictional properties	Mildly alkaline (8-10) – leachate can be 11
Great resistance to stripping and rutting	Potential to retain water – instability
High stability	Tufa precipitates potential: clogs drainage
Retains heat longer – good for cold weather	Higher absorption – high specific gravity
Good durability and resistance to weathering	Higher asphalt cement demand
May be more economical than traditional fillers	

Standard Specifications

ASTM D5106:	Steel slag aggregates for Bituminous Paving Mixtures
ASTM D4792:	Standard Test Method for Potential Expansion of Aggregates from Hydration Reactions
AASHTO T19:	Standard Method of Test for Bulk Density and Voids in Aggregate
AASHTO T96:	Standard Method of Test for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
AASHTO T104:	Standard Method of Test for Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate

State Mentioned Specifications

AASHTO T85:	Specific Gravity of Course Aggregate
AASHTO T176:	Plastic Fines in Graded Aggregates and soils by use of the Sand Equivalent Test
ASTM C295:	Standard Guide for Petrographic Examination of Aggregates for Concrete
AASHTO T112:	Clay Lumps and Friable Particles in Aggregate
ASTM M323:	Standard Specification for Superpave Volumetric Mix Design
ASTM D4791:	Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate
AASHTO T11:	Materials finer than No.200 sieve in Mineral Aggregate by Washing
AASHTO T27:	Sieve Analysis of Fine and Course Aggregates
AASHTO M80:	Specification for Coarse Aggregate for Hydraulic Cement Concrete
AASHTO T113:	Lightweight Pieces in Aggregate

State Specific Specifications

PTM No.130	Method of Test for Evaluation of Potential Expansion of Steel Slags
PTM No.510:	Sulfate Soundness
PTM No.622:	Abrasion Testing
MP 703.00.25:	Method of Determination of Percent of Thin or Elongated Pieces in Course Aggregate
MP 703.00.27:	Standard Method of Test for Percent by Weight of Shale in Crushed Aggregate
MP 702.01.20:	Standard Method of Test for Determining the Percentage of Coal and Lightweight Particles in Aggregate

MP 703.01.20: Standard Method Test for Friable Particles in Aggregates
MP 703.00.22: Soundness of Aggregates Using Sodium Sulfate

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	No	-	Allows air-cooled blast furnace slag
District of Columbia	No	-	Allows air-cooled blast furnace slag
Pennsylvania	Yes	Fine Aggregate **703.1** Course Aggregate **703.2(a)(4)** Follows General Permit WMGR101	May use for fine aggregate for bituminous but not along with course slag aggregate. Fine and Course Conforms to **ASTM C295** and **PTM No. 130** – expansion less than 0.5% Table B – Type B - **PTM No.510** – Max % loss = 12% **PTM No.622** – Max % wear = 45%
Maryland	Yes	Chip seal surface treatment Only **901.01.01** Follows 503	Chip seal surface treatment conforms to **AASHTO M80** Class A and **ASTM D4792** – expansion < 1.5% **ASTM T85** –absorption shall not vary more than 0.2% **ASTM T112** – shall have < 4% soft particles
New Jersey	No	-	Asphalt Concrete Industry in state does not want to deal with steel slag
New York	No	-	Chemistry of steel slag limits/prevents use in asphalt
Virginia	No	-	Allows air-cooled blast furnace slag
West Virginia	Yes	Surface Treatment and HMA **703.3** Follows 401, 402 and 405	**AASHTO T19/T19M** weight > 70pcf May use electrometallurgical slag **MP 7003.00.25** Max % elongated = 5% **MP 703.00.27** Max shale = 1% **MP 702.01.20** Max coal & deleterious = 1.5% **MP 703.01.20** Max friable particles = 0.25% **MP 703.00.22** (sodium sulphate) Max loss = 12% **AASHTO T96** – Max % wear = 40%

Recommendation/Comments

Only three states allow the use of steel slag as an aggregate but three other states allow the use of air-cooled blast furnace slag as an aggregate for asphalt concrete. The main issues with steel slag have been the time to stockpile and hydrate as well as the expansion within the application. Test methods such as ASTM D4792 deals with the expansion issues. The states also differ in AASHTO T96 and AASHTO T104 as shown below. If this is harmonized, ASTM D4791 and ASTM D5106 are recommended to use.

GROUND GRANULATED BLAST FURNACE SLAG

Application: Cement Concrete (Cementitious Material)

Advantages	Disadvantages
Used since the beginning of the 1900's	*Slower setting rate*
Can substitute 30-45% of cementing material	Susceptible to salt scaling
Less energy to process than cement	Loss of durability from salt scaling
Enhanced workability and strength	
Decreases water demand	

Standard Specifications

AASHTO M240: Standard Specification for Blended Hydraulic Cements

AASHTO M302: Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars

ASTM C441: Standard Test Method for Effectiveness of Pozzolans or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction

State Mentioned Specifications

ASTM C672: Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemical

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	Yes	Blended **801**	Conforms to **AASHTO M240**
		Pozzolan **812.02**	Conforms to **AASHTO M302**, Grade 100 or 120 Substitute 35-50% of PC
District of Columbia	Yes	Blended **801.03**	Conforms to **AASHTO M240**
		Pozzolan **801.04**	Conforms to **AASHTO M302**, Grade 120 Use up to 40% slag
Pennsylvania	Yes	Blended **704.1(h)3b**	Conforms to **AASHTO M240** **ASTM C441** – 50% min. -Use min 40% of total cementitious material If **AASHTO TP14** >0.4%
		Pozzolan **724.3**	Conforms to **AASHTO M302**, Grade 100 or 120 Do not use if material temp > 180°F at delivery
Maryland	Yes	**Blended not allowed**	Not considered yet. Looking into
		Pozzolan **902.03.02**	**AASHTO M302**, Grade 100 or 120. 25- 50% substitute
New Jersey	No	Blended **903.01**	Conforms to **AASHTO M240** Max of 50% slag by weight > 30% slag, **ASTM C672** Note: If used for ASR – use at least 25%

		Pozzolan **903.03.03**	Conforms to **AASHTO M302**, Grade 120 (Grade 100 with permission from the ME) Max of 50% replacement of cement If more than 30% slag **ASTM C672** ~Portland cement concrete industry does not want to deal with steel slag so have no pursued use in PCC
New York	Yes	Blended **701-03** Pozzolan **711-12**	Conforms to **AASHTO M240** < 22% by weight Conforms to **AASHTO M302**, Grade 100
Virginia	Yes	Blended **214** Pozzolan **215**	Conforms to **AASHTO M240** (IS) Conforms to **AASHTO M302**, Grade 100 or 120 **ASTM C441** – *max* expansion of 0.1% at 56 days. Max of 50% by weight
West Virginia	Yes	Blended **701.3** Pozzolan **707.4.2**	Conforms to **AASHTO M240** (IS) Conforms to **AASHTO M302** (Tables I and II except for slag activity index- does not apply)

Recommendation/Comments

All states use GGBFS in cement concrete and blended cements except for Maryland, which excludes GGBFS from blended cements. The main difference in the states is the grade of slag allowed. Most allow both grade 100 and 120, with the exception of NY, only allowing grade 100 and DC, only allowing grade 120. If there are issues with ASR, ASTM C441 would be recommended. For all other cases, AASHTO M240 and AASHTO M302 would be recommended.

GROUND GRANULATED BLAST FURNACE SLAG

Application: Flowable Fill

Advantages	Disadvantages
Increases the performance of the fill Can be used alone as binder or with PCC Saves energy and reduces carbon dioxide emissions Reduced heat of hydration Improved resistance to sulfate attack	No real specification for flowable fill

Standard Specifications

AASHTO M302: Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars

ASTM C441: Standard Test Method for Effectiveness of Pozzolans or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction

State Mentioned Specifications

AASHTO T23: Making and Curing of Concrete Test Specimens

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	Yes	**Special Provision 208500**	**AASHTO M302**, Grade 100 or 120 % of substitution is based on strength testing
District of Columbia	No	-	
Pennsylvania	Yes	**220.2(c)**	Conforms to **AASHTO M302**Grade 100 and 120 From source in Bulletin 15
Maryland	No	-	Not considered
New Jersey	No	-	Portland cement industry does not want to deal with steel slag so they have no pursued use in flowable fill
New York	No	-	Chemistry of steel slag limits/prevents use in flowable fill
Virginia	Yes	Special Provision **S302G01-0908** Pozzolan Follows 215	Conforms to **AASHTO M302**, Grade 100 or 120 **ASTM C441** – max expansion of 0.1% at 56 days. Max of 50% by weight
West Virginia	No	-	They don't know why

Recommendation/Comments

Only three states allow the use of GGBFS in flowable fill. Those that do allow the use conform to AASHTO M302, which would be the recommended specifications. This is a low value application and mainly used with fly ash rather than slag, so the volumes typically used are quite small. This application would not be recommended to be harmonized because it is of low priority.

AIR-COOLED BLAST FURNACE SLAG

Application: Cement Concrete Course Aggregate

Advantages	Disadvantages
Used internationally – successfully used	Can expand by 10% in humid climates
Can improve concrete performance	Leachate mildly alkaline – metal corrosion
Better particle shape – rougher texture	Potential to retain water – instability
Less chance of alkali-aggregate reaction	Variability in physical properties
Retains heat longer – good for cold weather	Higher absorption – more cement and water needed
Good durability and resistance to weathering	

Standard Specifications

AASHTO T19: Standard Method of Test for Bulk Density and Voids in Aggregate

AASHTO T303: Standard Method of Test for Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction

AASHTO T104: Standard Method of Test for Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate

AASHTO T96: Standard Method of Test for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

State Mentioned Specifications

AASHTO T85: Specific Gravity of Course Aggregate

AASHTO M80: Standard Specification for Coarse Aggregate for Hydraulic Cement Concrete

ASTM C294: Standard Descriptive Nomenclature for Constituents of Concrete Aggregates

ASTM C563: Standard Test Method for Approximation of Optimum SO_3 in Hydraulic Cement Using Compressive Strength

AASHTO T11: Materials finer than No.200 sieve in Mineral Aggregate by Washing

AASHTO T112: Clay Lumps and Friable Particles in Aggregate

AASHTO T113: Lightweight Pieces in Aggregate

ASTM D4791: Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate

State Specific Specifications

MP 703.00.25: Method of Determination of Percent of Thin or Elongated Pieces in Course Aggregate

MP 703.00.27: Standard Method of Test for Percent by Weight of Shale in Crushed Aggregate

MP 702.01.20: Standard Method of Test for Determining the Percentage of Coal and Lightweight Particles in Aggregate

MP 703.01.20: Standard Method Test for Friable Particles in Aggregates

MP 703.00.22: Soundness of Aggregates Using Sodium Sulfate

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	No	-	Never been requested to use as aggregate
		805	**AASHTO M80, AASHTO T19** Must weight > 70pcf Conforms to **AASHTO T96** - % wear < 45%
District of Columbia	No	**803.02**	**AASHTO M80, AASHTO T96** (LA abrasion < 40), **ASTM C294** (Gs > 2.88), **AASHTO T104** weighted % loss < 15% when subjected to 5 cycles
Pennsylvania	No	-	Not allowed in cement concrete
Maryland	No	-	Not considered
New Jersey	No	-	Portland Cement Concrete Industry in state does not want to deal with steel slag so don't use
		901.06 Follows 901.04 and 903.03.01	Min of 60pcf for **AASHTO T19**, Max of 50% for **AASHTO T96**, Max of 2% for **ASTM C563** **AASHTO T303** < 0.1% after 14 days
New York	No	**703-0204**	**AASHTO T104 -** Max % loss at 10 cycles = 6% **AASHTO T96 -** Max % loss = 40% Min unit weight = 70pcf – Max % metal ore = 3% Max % other deleterious = 3% - Max Total del = 5% Must meet Table 703-4 (Sizes of Slag)
Virginia	Yes	**217.02(d)** Follows 203.02	**AASHTO T19** *free of foreign minerals and glassy* pieces 70 lb/ft^3 small sizes, 65lb/ft^3 larger sizes **AASHTO T104** Max % loss = 12% after 5 cycles (5% at 100 cycles) **AASHTO T96** Max % wear = 45% (500Rev) **AASHTO T113** – Max coal and lignite = 0.25% **AASHTO T112** – Max clay lumps = 0.25% **AASHTO T11** – Max passing No.200 = 1.0% **ASTM D4791 -** < 30% by mass of aggregate retained on 3/8 in – has max to min ratio > 5
West Virginia	Yes	**703.3** Follows 501	**AASHTO T19** weight > 70pcf for PCC Other slags allowed if approved by Engineer *may not use Electrometallurgical slag and Power plant slag for PCC aggr. **MP 703.00.25** Max % elongated = 5% **MP 703.00.27** Max shale = 1% **MP 702.01.20** Max coal and deleterious= 1.5% **MP 703.01.20** Max friable particles = 0.25% **MP 703.00.22** (sodium sulphate) Max loss = 12%

Recommendation/Comments

Only two of the states allow the use of air-cooled blast furnace slag as an aggregate in cement concrete. The other states have specifications but do not allow the use. This is not a typical use of slag and not a priority to harmonize.

AIR-COOLED BLAST FURNACE SLAG

Application: Granular Base or Sub-base

Advantages	Disadvantages
Used in the US and internationally	Not economical if low quality aggregates is suffice
Performs like conventional aggregate	Limited data on testing and assessing suitability
High bearing capacity – good on weak subgrade and heavy traffic	Volumetric instability – expansive potential
High stability and good soundness	Potential for tufalike precipitates – Clog drains
High specific gravity – aggregate yields higher density than conventional	Tufa creates water retention – may freeze – crack pavement
Free-draining – not susceptible to frost	Weathering doesn't prevent formation of tufa

Standard Specifications

ASTM D4792:	Standard Test Method for Potential Expansion of Aggregates from Hydration Reactions
AASHTO T103:	Standard Method of Test for Soundness of Aggregate by Freezing and Thawing
AASHTO T104:	Standard Method of Test for Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate
AASHTO T96:	Standard Method of Test for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
AASHTO M147:	Standard Specification for Materials for Aggregate and Soil-Aggregate Sub-base, Base, and Surface Course

State Mentioned Specifications

ASTM C295:	Standard Guide for Petrographic Examination of Aggregates for Concrete
ASTM D4791:	Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate
AASHTO T11:	Materials finer than No.200 sieve in Mineral Aggregate by Washing
AASHTO T19:	Standard Method of Test for Bulk Density and Voids in Aggregate
AASHTO T27:	Sieve Analysis of Fine and Course Aggregates
AASHTO T87:	Dry Preparation of Disturbed Soil and Soil Aggregate Samples for Test
AASHTO T89:	Determining the Liquid Limit of Soils FOP for AASHTO
AASHTO T90:	Determining the Plastic Limit and Plasticity Index of Soils
AASHTO T180:	Standard Method of Test for Moisture-Density Relations of Soils Using a 4.54- kg (10-lb) Rammer and a 457-mm (18-in.) Drop
AASHTO T193:	Standard Method of Test for the California Bearing Ratio

State Specific Specifications

VTM-7	Virginia Test Method: Atterberg Limits (AASHTO T89 and T90)
VTM-25	Virginia Test Method: Dry Preparation, and Mechanical Analysis of Soils, Select Material, Sub-base, and Aggregate Bases (AASHTO T27 and T87)

MP 700.00.0: Aggregate Sampling Procedures
MP 702.01.20: Standard Method of Test for Determining the Percentage of Coal and Lightweight Particles in Aggregate
MP 703.00.22: Soundness of Aggregates Using Sodium Sulfate
MP 703.00.27: Standard Method of Test for Percent by Weight of Shale in Crushed Aggregate
MP 703.01.20: Standard Method Test for Friable Particles in Aggregates

State Specifications

State	Use?	Spec Number	Comparison to Standards
Delaware	No	-	Never been requested for use
District of Columbia		**804.04(c)**	Conforms **to AASHTO M147** for Bases Min CBR of 25 from **AASHTO T193** when using **AASHTO T180**-Method D – hard and durable particles 100% passing 2in, 95-100% 1.5in, 70-92% passing ¾ in 50-70% passing 3/8in, 35-55% passing No.4, 12-25% passing No.30, 0-8% passing No.200
Pennsylvania	Yes	Steel slag **703.2(a)4** GGBFS **703.2(a)5** Follows 350 and General Permit WMGR101	Both Conforms to **ASTM C295** GGBFS – Contains < 3% total iron as Fe_2O_3 Use material < 20% by mass not GGBFS **PTM No.609** Density < 80pcf Uniform material – max size of 2in < 20% passing No.100 sieve
Maryland	No	-	Not planning to use for base/sub-base at this time
New Jersey	No	-	Concerns for expansive potential
New York	No	-	Chemistry of slag limits use in base/sub-base
Virginia	Yes	Base and Sub-base **208.02**	**VTM-25** (**AASHTO T27** and **T87**) **VTM-7** (**AASHTO T89** and **AASHTO T90)** **AASHTO T103 or T104** Max loss = 30% (5 cycles) and 12% (100 cycles) **AASHTO T96** Max loss = 45% (500Rev) **ASTM D4791** Max flat and elongated = 30%
West Virginia	No	**704.6** Follows 703.3	Crushed slag - **AASHTO T19** weight > 60pcf Uniform and free from dirt Blast Furnace Slag - Sampled by **MP 700.00.06** **MP 703.00.22** (Max loss = 12%) **AASHTO T89** (LL), **AASHTO T90** (PI), **ASTM C295**, **MP 703.01.20**, **MP 702.01.20** and **MP 703.00.27 (Delet.)** **AASHTO T11** and **AASHTO T27 –** Gradation **AASHTO T96** – Max % wear = 40%

Recommendation/Comments

Only two states allow the use of air-cooled blast furnace slag in bases/sub-bases. Not a priority materials/application.

Appendix B: State-by-State Environmental Regulation Summaries and Comparison Matrix

DE Beneficial Use Program

Department of Natural Resources and Environmental Control (DNREC)

The Delaware Administrative Code, Title 7: 1300 describes the regulations for recycling solid waste in Delaware. Within this, 1301 Regulations Governing Solid Waste regulates the handling and processing of waste materials. The Solid and Hazardous Waste Management Branch (SHWMB) evaluates and records the beneficial use of materials such as construction and demolition materials, coal combustion by-products and scrap tires.

Specifically, Section 2.5 regulates Delaware composing and recycling approvals. Written approval is required in order to recycle solid waste, which includes an application involving the types of materials to be reused, the processing methods and equipment needed, and documentation showing there is a need to market the product. Within 60 days after receiving the application, a final determination will be made, given there is no negative comments from the department. From here, they will either issue or deny the permit, including reasons for refusal if denied. The department has the right to inspect before and after the permit has been given to assure the user is complying with the regulations of the permit. DNREC does not currently have specifications that regulates the beneficial use of industrial material but are looking to create a guidance document for beneficial use determinations.

DC Beneficial Use Program

Nothing Found.

Maryland Beneficial Use Program

Department of the Environment

The Code of Maryland Regulations (COMAR) identifies the restrictions of solid waste to be beneficially used for highways applications. Generally, solid waste may only be handled in a way that will refrain from causing a nuisance, polluting the air or water, or creating a hazard to public health or safety. Specifically, Maryland has regulations on recycling scrap tires and coal combustion byproducts (CCBs) but does not mention the beneficial use process for any other industrial waste material.

Recycling or processing scrap tires must follow the regulations found in COMAR 26.04.08; licensing is required to handle and process scrap tires under COMAR26.04.08.08. Storing of scrap tires follows COMAR 26.04.08.17, including plans for controlling potential fires or preventing leaching. These regulations were designed similar to the National Fire Protection Association (NFPA)'s "Standard for Storing of Rubber Tires" (1989 Edition). The Department may suspend any beneficial use of scrap tires under COMAR 26.04.08.25 if they find the person requiring the permit included inaccurate information, or broke the terms or requirements to use the scrap tires. Finally, there is a Tire Clean-up and Recycling Fund that can be used and supports the recycling of scrap tires, found under COMAR 26.04.08.26.

Currently, there is a proposed regulation for the beneficial use of CCBs in Maryland, which potentially will be found under COMAR 26.04.11. The proposal explains that the economical impact will not be significant, as the costs for increased analytical testing more than offset the costs avoided from disposing the waste in landfills. Leachability testing may not exceed the Maximum Contaminant Levels (MCL) specified in COMAR 26.04.01.06.

The new regulations will require lower limits for the analytical tests and increased environmental monitoring, which will require approval beforehand. Under COMAR 26.04.11.05, the Department proposes to allow the use of CCBs as an additive or replacement of cement, concrete and asphalt. Under COMAR 26.04.11.06, the Department will allow the use of bottom ash for a substitute for aggregate for asphalt and concrete, structural aggregate, flowable fill, and a winter traction control aid. Finally, the beneficial use of CCBs requires annual reporting describing how much materials were used and the resulting data from the leachability and analytical testing.

New Jersey Beneficial Use Program

Solid and Hazardous Waste Management Program

In order to beneficially reuse a waste product in transportation projects in the state of New Jersey, Certificates of Authority (CAO) are obtained, showing that the material meets solid waste regulations and are no longer considered a solid waste in accordance with N.J.A.C 7:26 et. seq (New Jersey Counseling Association). To date, over 290 CAO's have been issued for different materials to be beneficially reused throughout the state. Certain pre-determined materials are exempt from the approval process, including materials from recycling centers, tires used for asphalt pavement, and coal ash (fly and bottom) used for aggregate in concrete, all found in N.J.A.C 7:26-1.7(g).

The submission requirement to obtain a CAO begins with a letter from the generator, certifying that the material has been analyzed and does not contain contaminants that would classify the solid waste as hazardous. It must be sampled and assured that it meets the DEP standards before being beneficially used, in accordance with N.J.C.A. 7:26E. For those materials used for direct land applications, more stringent limits are required to guarantee the groundwater will not be negatively impacted from the addition of the recycled product.

Out-of-state shipments of solid waste materials for beneficial use projects are allowed in New Jersey, though they require documentation supporting the proof that the material does not contain any contaminants that would adversely affect human health and the environment. The Department will issue or deny the Certificate of Authority within 90 days for in-state projects and 45 days for out-of state.

NY Beneficial Use Program

Department of Environmental Conservations

Beneficial Use Determinations (BUDs) in New York are obtained if a solid waste material can be reused or recycled beneficially in another project under 6 NYCRR Part 360 (NY Codes, Rules and Regulations) of the Solid Waste Management Facilities Regulations. Once obtained, the material is no longer considered a solid waste and may be recycled, assuming there are no adverse affects to human health or the environment. BUDs are similar to permits, but they do not need to comply with 6 NYCRR Part 617 or 621 in the review process.

There are sixteen pre-determined BUDs located in 6 NYCRR Part 360-1.15(b) which are considered recyclable materials and may be used for certain applications, though some may need special testing and permits. Some pre-determined BUDs include: tire chips used as aggregate for road bases or asphalt pavement, coal fly ash for flowable fill and both fly and bottom ash for cement or aggregate in concrete or structural fill. Some special reporting is necessary for coal combustion generators, who are allowed less than 60 days after the first of January of each year to report how much coal ash was distributed to roadways, parking lots, and used in concrete, structural fill, flowable fill, etc.

In order to acquire a BUD for case-specific recyclable materials and applications, a petition is required in accordance with 6 NYCRR Subdivision 360-1.15(d) to evaluate the potential beneficial use of a waste product. This petition includes a description of the solid waste, its source and its proposed use, chemical and physical characteristics, a demonstration that the proposed use of the material will meet specifications, and a waste control plan including storage and best management practices. For those seeking a BUD, The department will consider the potential possibility of improper handling, transportation and storage, which could lead to adverse affects on public health and safety, the environment and natural resources.

Pennsylvania Beneficial Use Program

Bureau of Waste Management

The beneficial use program of solid waste materials can be described in the Pennsylvania Code, specifically in Chapter 287. According to Section 287.7 of the Code, waste can be used with a permit if it meets the terms of the permit and does not harm public safety, health or the environment. Wastes do not need to be regulated if they will be used or reused for an industrial process or substitute the waste for a raw material; nor do they regulate co-products which are materials generated by manufacturing processes, such as spent foundry sand, coal ash or steel slag. The general requirements and exemptions for a permit can be found in Section 287.101 of the Code.

The department may decide after processing the waste that it can be beneficially used even if it does not meet the co-product requirements found in Section 287.8 and 287.9 in the Pennsylvania Code. Co-products may be used as an ingredient in the manufacturing process or as a substitute for a commercial product, assuring the physical and chemical compositions of the material will not change over time and will not threat human health or the environment. The co-products must be evaluated for hazardous or toxic constituents, or those constituents in 40 CFR Part 261, Appendix VIII using "Test Methods for Evaluating Solid Waste" (EPA SW 846).

There are a number of special provisions for certain materials and their use. Reclaimed materials looking to be beneficially must follow the Permit-by-rule (found in Section 271.103 or 287.102) for on-site, or the General Permit (Section 271.821 or 287.621) and the Processing Permit (Section 283.1 or 297.1) for off-site. Waste tires can be recycled through the General Permit for Processing and Beneficial Use of Waste Tires (WMGR038).

Coal Ash may be used in a number of ways, including structural fill, soil substitute, concrete, aggregate, or a drainage layer; the different applications follow the regulations in Section 287.661, 287.662, and 287.665 of the Pennsylvania Code, requiring the submission of a written notice to the Department, stating environmental testing has been done and levels do not exceed the material it is replacing. Coal ash to be reused must fill out the Application for a Determination of Applicability for Beneficial Use of Coal Reuse 2540-PM-LRWM0003.

The Department may void the permit and thus be considered waste if the material does not operate consistently under the terms and conditions, or meet the requirements of Section 287.7 of the Code.

Virginia Beneficial Use Program

Department of Environmental Quality

When a solid waste is analyzed and granted a proposed beneficial use, it is no longer considered solid waste, and does not need to be regulated. Virginia's laws allow any material to be beneficially used, though many prefer to obtain an official beneficial use determination (BUD) so to not incur liability of improper use or disposal. The Solid Waste Management Regulations in Chapter 80 of the Virginia Administrative Code explain the steps needed to dispose of solid waste, while Sections 9VAC20-80-150 and 9VAC20-80-160 describes the exemptions from these regulations when the waste is used beneficially. Some of these exemptions include using a solid waste as an ingredient for an industrial process, substituting for a natural resource, or using wastes created from processing ores.

Specifically, coal combustion byproducts (CCB) may be used as a material for other products such as concrete, lightweight aggregate or flowable fill. In cases where CCBs do not comply with the exemption sections, they may be used in accordance with the CCB regulations in Chapter 85 of the Virginia Administrative Code, which establishes standards and procedures to recycle the material.

Waste tires stored at salvage yards licensed by the DMV may be beneficially used as a sub-base fill for a road-base or used in asphalt pavement when approved by the Virginia Department of Transportation. In cases where waste tires are not exempt under 9VAC20-80-60 (D11) or 9VAC20-80-160 (A6), a permit must be obtained in accordance with the standards in 9VAC20-80-340 or 9VAC20-80-400, including a contingency plan. Tires have a specific section (9VAC20-80-670) which explains the storing procedure to reduce the possibilities of combustion and fire.

Other case-specific determinations require a number of information from the requestor in order to make sure the proposed use will not adversely affect human health or the environment, found in 9VAC20-80-160. Some of these include: a description of the solid waste and its proposed use, the chemical and physical characteristics, and a demonstration that the proposed use is marketable and complies with all the standards and specifications. The requestor must provide a control plan with testing, storage and run-off control procedures, along with a contingency plan in-case of an emergency. The department will determine within 90 days if the proposed use constitutes a beneficial use determination. This will be approved, denied, or allowed under certain conditions and may be revoked if there is any violation or the process becomes a nuisance.

WV Beneficial Use Programs

Department of Environmental Protection

The general requirements for recycling solid waste can be found in the W.Va. Code §22-15-1 et seq as well as the Solid Waste Management Rule, found in Title 33 Legislative Rule by the Department of Environmental Protection. The beneficial use of coal combustion by-products can be found in the Legislative rule Series 1, while the beneficial use of waste tires is found in Series 5, known as the Waste Tires Management Rule. These requirements were based on the potential quantity of waste handled, the potential environmental impacts, the characteristics of the wastes and the requirements for roadway standards. The director may issue or refuse a permit in cases where the material facts were misrepresented or violates the environmental laws.

The beneficial use of coal combustion by-products can be found in Legislative Rule §33-1-5.5.b.4, which does not require a permit and may be used as a component in concrete, road bases and sub-bases, flowable fill and lightweight aggregate. It may also be used for pipe bedding or as a composite liner drainage layer. Bottom ash may be used as an anti-skid material, but fly ash is not permitted for this use. For future rule-making, West Virginia plans to include uses of coal combustion by-products in structural fills and soil modification.

Waste tires can be beneficial used when meeting the requirements of W.Va. Code §22-15-21, §17-23 and Legislative Rule §33-5. Under the legislative mandate, it is unlawful to dispose of waste tires in landfills, unless used in WVDOT tire remediation programs or in cases where there is no alternative disposal option. If the applicant is only recycling one hundred waste tires or less, they are not required to obtain a permit. Otherwise, a permit but be acquired from the Department of Environmental Protection to generate, collect, store or manage the tires. Waste tires are allowed to be beneficially used as an alternative fuel, in civil engineering applications, or as a daily cover at a waste landfill.

In order to obtain a permit for beneficially using waste tires, the applicant must submit a report including a number of regulatory requirements; these include a proposed annual tonnage of waste to be processed or stored, an emergency response plan including potential fires, and a method to protect groundwater from contamination. Additionally, facilities storing waste tires must be designed to handle them with the required space and a vector control plan to control and/or prevent disease carrying insects or rodents. Finally, quarterly and semiannually reports must be written and submitted to record the quantity and origin of the waste tires, as well as any problems or changes made.

Environmental Regulations Matrix

	Maryland	New Jersey
Location of Regulations	Code of Maryland Regulations (COMAR) **COMAR 26.04.08** - Recycling Scrap Tires **COMAR 26.04.10** - Managing and Recycling CCBs **Proposed: COMAR 26.04.11** - Beneficial Use of CCBs	New Jersey Counseling Association - N.J A C **N.J.A.C. 7:26** - Solid Waste Regulations Guidance Document for Beneficial Use Project Approval Process
Predetermined Material/Applications	**Proposed: COMAR 26.04.11.05 and 26.04.11.06** Including: CCB as additive in concrete and asphalt, Bottom ash as substitute for aggregate for concrete, asphalt and flowable fill, and winter traction aid	**N.J.A.C. 7:26 - 1.7(g)** Chip tires as aggregate for road base Coal fly ash used as lightweight aggregate Fly and Bottom ash as component or aggregate in cement or concrete Fly and bottom ash as aggregate in structural asphalt Fly and bottom ash aggregate in sub-base roadway construction
Predetermined Requirements	Does not relieve user from permitting for wetlands, grading stormwater plan approcal or zoning approval Analytical data that material is not leachable using Solids analysis, leachability tests, Montioring and Testing below	Used in accordance with **N.J.A.C. 7:26-1.1** Application - description of project, site location map, description of material Documentation of contaminant concentrations, quality assurance procedures Annual reports - volume used, dates and locations of use
Case Specific Requirements (No permit)		**N.J.A.C 7:26** (except **N.J.A.C. 7:26-1.7(g)**) *Letter from Generator - certifying material - testing concentrations, etc* Letter from receiving facility - proposed use, details of project, volume, dates Testing requirements below May not pose greater risk to health and envionment than material replacing Must meet purpose and intent of **N.J.S.A 13:1E-1 et seq and specs**
General Permit Requirements	**COMAR 26.04.08.08** - Scrap Tire Recycler License Procedure Application - information on facility, method of storage Proposed type and quanity of tires, ability to meet storage zoning and land use requirements	
Permits/Special Provisions		
Testing Required	**COMAR 26.04.01.06** - Leachability Testing - CCB **COMAR 26.04.11.09** - CCB Environmental Monitoring **TC - 6.10** - May require TCLP testing for: Crumb rubber, Blast Furnace Slag and Coal Fly ash	Sampled and analyzed in accordance with **N.J.A.C. 7:26E** (DEP quality assurance) Dioxin/furan testing - (SW 846 Method 1613B)
Extra Reporting Required	**COMAR 26.04.11.10** - CCB Annual Reporting Includes Annual volumes generated, used and where went Leachability or solids anaylsis data	
Organizations Involved	Department of the Environment Tire Clean-up and Recycling Fund	Department of Environmental Protection Solid and Hazardous Waste Management Program Bureau of Landfill and Hazardous Waste Permitting

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	Virginia	West Virginia
Location of Regulations	Virginia Administrative Code (VAC) **9VAC20-80** - Solid Waste Manageme **9VAC20-80-670** - Scrap Tires **9VAC20-85** - Coal Combustion Bypro	West Virginia Code (W.Va. Code)
Predetermined Material/Applicatio	**9VAC20-80-150 and 9VAC20-80** Including CCB used in concrete, flow abl sub-base, embankment, or base Waste *Bottom ash for road surface material and* Chipped waste tires as drainage material	
Predetermined Requirements	**9VAC20-85-150** - CCBs require desc chemical and physical description, oper	
Case Specific Requirements (No permit)	**9VAC20-80-150E2(b)** - requestor re use, chemical and physical characteristi Demonstration that purpose complies wi Solid Waste control plan - periodic testin Contingency plan - evacuation plan -	
Testing Required Extra Reporting Required	**9VAC20-85-90** - Surface Runoff co TCLP testing - CCBs	
Organizations Involved	Department of Environmental Quality Office of Pollution Prevention Waste Tire Management Program	Department of Environmental Protection Waste Tire Remediation Program Office of Waste Management

	New York	Pennsylvania
Location of Regulations	NY Codes, Rules and Regulations (NYCRR) **6 NYCRR Part 360** - Solid Waste Management Facilities Regulations	**Pennsylvania Code §287.7** - Material is no longer Waste **Pennsylvania Code §287.8** - Coproduct Determination **Pennsylvania Code §287.9** - Industry-wide Coproduct Determinations
Predetermined Material/Applications	**6 NYCRR Part 360-1.15(b)** Including Tire chips for aggregate in road base or asphalt *Fly ash for flowable fill* Fly ash and bottom ash in cement or aggregate for concrete or structural fill	**Pennsylvania Code §287.661** - Coal ash as structural fill **Pennsylvania Code §287.662** - Coal Ash as Soil Substitute or Soil Additive **Pennsylvania Code §287.665** - Coal ash in Manufacture of Concrete, Fly ash as stabilized product, Bottom ash as antiskid material and construction aggregate Coal ash as drainage material or pipe bedding
Predetermined Requirements	**6 NYCRR Part 360-1.15(c)** Coal ash - submit a report - Volumes generated and used for each application	Department requires notice w/ purpose and location of project, dates, volume of material to be used Construction plans by registered PE (structural fill) Chemical and Leaching Analysis (structural fill, soil substitute or additive, pipe bedding or drainage material **§299.153** - Storage of coal ash
Case Specific Requirements (No permit)	**6 NYCRR Part 360-1.15(d)** Description of solid waste and proposed use Chemical and physical characteristics Demonstration that use will follow specifications Waste control plan - storage and Best management practices Marketability Analysis - periodic testing	Use will not harm human health, safety or welfare of environment Physical and chemical composition may not interfere with usefulness May not present greater threat than application replacing
General Permit Requirements		**Pennsylvania Code §287.621** - Application for General Permit Description of waste covered by permit, proposed use and manufacturing and production process physcial and chemical characteristics - *Analysis* **(§287.132)** Proposed concentration limits for contaminants in waste and reason Demonstration that waste meets performance standards of ASTM, DOT's or other standards Roadway applications require approval from Department of Transportation Porudtc Evaluation Board

Permits/Special Provisions		**2540-PM-LRWM0003** - Application for a Determination of Applicability for Beneficial Use of Coal Refuse Ash **General Permit WMGM039** - Pre and Post-Consumer Asphalt Shingles **General Permit WMGR038** - Processing and Beneficial Use of Waste Tires **General Permit WMGR019** - Beneficial Use of Waste Foundry Sand **General Permit WMGR101** - Beneficial Use of Steel Slag **General Permit WMGR042** - Beneficial Use of BOP Slag Fines
Testing Required		evaluate hazardous or toxic constituents **(40 CFR Part 261 Appendix VIII)** "Test Method for Evaluating Solid Waste" (EPA SW-846) Toxicity Characteristic and leaching procedure (EPA Method 1311) or synthetic precipitation testing (Method 1312) EPA Method 600/R-93-116 or OSHA Method Number ID-191 for scrap shingles
Extra Reporting Required		May require submitting periodic reports or analyses to ensure quality
Organizations Involved	Department of Environmental Conservations	Bureau of Waste Management Penn Waste Tire Recycling Program *Department of Environmental Protection*

Appendix C: Priority Short List

Primary Materials/Applications Considered for May's Workshop on Standardization Harmonization

Yes

<u>Fly ash - Concrete SCM/Blended</u>

AASHTO M295: Coal fly ash and Raw or Calcinated Natural Pozzolan in Concrete
AASHTO M240: spec for blended hydraulic cement

Used for 60 years – well known
May reduce costs
Increase durability, cohesion of paste, workability
Reduced bleeding, permeability, shrinkage cracking, water demand
Slower strength development – longer setting time
All states use conform to ASTM C618 and ASTM C595

<u>Fly ash - Flowable Fill</u>

AASHTO M295

Used since 1960's
Can be less expensive than sand if easily available
Improved long term strength – Less cement needed – Can be placed in freezing weather
Potential to leach metals – no set proportioning
All states use application
All states use ASTM C618 but NJ

<u>Ground Granulated Bast Furnace Slag – Concrete SCM/Blended Cement</u>

AASHTO M302: Standard Specification for GGBFS for use in concrete
ASTM C441: Test method for Pozzolan in preventing expansiveness in concrete
AASHTO M240 – Standard Spec for Blended Hydraulic Cements

Used since beginning of 1900's
Can substitute 30-45% cementing material
Less energy to process – better workability and strength
Slower setting time
All states have specs for use except NJ – Maryland doesn't allow blended
Concrete industry in NJ doesn't want to deal with steel slag

<u>Scrap Tires - Embankment/Fill</u>

ASTM D6270: Standard Practice for Use of Scrap Tires in Civil Engineering Applications

Used by 15 states – over 70 successful projects
Reduced unit weight – good on low bearing capacity soils
Good drainage – similar to granular soils
Very economical compared to borrow
Tires are combustible – must take environmental precautions
Have some problems with compaction
NY and DE use and have special provisions – only DE follows ASTM D6270

NY suspended use because they did huge project to rid tires through embank.
DC, MD, WV do not use – hasn't been presented
PA is pending to use tires in embankments
NJ – contractor thinks tires are more trouble than worth –must pay premiums
VA allows use by select special provisions

<u>Steel Slag - Asphalt Concrete Aggregate (surface treatment)</u>

ASTM D5106: Steel slag aggregates for Bituminous Paving mixtures
Used internationally and successful – find case studies
May be more economical than traditional filler
Some expansive issues – may need to include spec on expansive testing
Great resistance to stripping and rutting – high stability – may need more asphalt
No states use this spec
PA, MD, VA, WV and maybe DC use this
DE – never requested use
NJ – asphalt concrete industry do not want to deal
NY says chemistry of steel limits/prevents use in asphalt

<u>Scrap Shingles - Asphalt concrete aggregate and binder</u>

AASHTO MP15: Spec for use of Reclaimed Asphalt Shingles as additive in HMA
AASHTO PP53: Standard practice for Design Considerations when using Reclaimed Asphalt Shingles in new HMA
Contains more than 30% of asphalt
As aggregate – reduces thickness of layer required – controls dust
As cold-patch mix – compares to high performance mix
Processing costs less than asphalt concrete
Concerns with asbestos – testing required
DE,PA,MD,NJ,VA use it and have specs for it – only PA uses MP15
NY does not allow tear off because of asbestos concerns
DE has never been requested to use tear-off
DC does not allow the use
NY do not use tear-off because of cost to clean out – producers reported difficulties getting consistent mix – do not use but willing to do test section
WV doesn't have enough of a supply to have spec

Maybe

<u>Fly ash - Embankment/Structural Fill</u>

ASTM E2277: Guide for Coal Ash for Structural Fills
ASTM E1266: Practice for Processing Mixtures of Lime and Fly Ash
Used since 1950's in US and internationally
Low unit weight compared with conventional
Compact ability in the winter time
May reduce construction time and costs
Dust control is an issue
Potential leaching into groundwater
Only DE has used it – no spec – used once in mid-90's – not typical application
Look into VA – says yes but not sure
DC, PA and MD don't allow the use
NJ says too many constraints to use fly ash as clean fill is cheaper and easier
NY has no specs though AASHTO is working on a spec – never used though

WV used to use but have been persuaded by environmental leaching claims
-allows use on special provision basis

Fly ash - Stabilized base

ASTM C593: Fly ash with Lime for Soil Stabilization
AASHTO TF28: using Pozzolans and Fly ash for in-place Soil Modifications
Used since 1950's
Excellent performance and improved strength
Little to no processing – increased stiffness
More economical than traditional base – less maintenance
Not applicable to highways – potential to leach
DC, PA and VA conform to C593
DE and WV do not use
MD says potential to leach metals into groundwater – Chesapeake Bay
NJ rarely does stabilized base – haven't done in over 20 years – case specific
NY doesn't prohibit but has not placed stabilized base in over 20 years

Scrap Tires - Asphalt cement Modifier or HMA fine aggregate

ASTM D6114: Specification for Asphalt-Rubber Binder
Increases stiffness at high temps – improved fatigue life
Resists reflective cracking
Reduced thickness of layer required
Performance varies – crumb rubber processing may cost more than asphalt
Limited data on emissions and environmental effect
DE, PA, NJ, NY, and VA allow use of it – none follow D6114
DC, MD do not use
NY has limited amount of asphalt binder, therefore no specs
WV looking into "mechanical concrete"
DE only state following D5461

Bottom ash - Embankment/Structural Fill

ASTM E2277: Standard Guide for Design and Construction of Coal Ash Structural Fills
Largest use of bottom ash – successful nationally and internationally
Free-draining – not typically susceptible to frost heave
Non-hazardous – good strength and compressibility
Potential to leach metals
Only WV will allow it for lightweight fill if needed – must clear with DEP
VA thinks ash has toxic metals that EPA won't allow in fills – Regs and monitoring was an enormous effort – tried to sign off for use
DE, DC, MD, NJ, NY do not use – not pursued
Should ask PA if they use

Ground Granulated Bast Furnace Slag - Flowable Fill

ASTM C989/AASHTO M302 – same as slag as pozzolan
ASTM C441 -Increases performance of fill
Saves energy, reduces CO2
DE, PA, VA use
Not considered in DC, MD or WV
NY says chemistry of steel limits/prevents use in flowable fill
NJ PCC industry does not want to deal with steel sla

Bottom ash - Stabilized Base Aggregate

AASHTO TF28: Specs for using Pozzolanic stabilized mixture and Fly ash for in-place Subgrade Soil Modification

ASTM C593: Spec for Fly ash and Other Pozzolans for use with Lime for Soil Stabilization

- Used successfully since 1950's
- Compacted unit weight lower than conventional
- Up to 95% replacement of aggregate
- No state uses this or has a spec for it

Air-Cooled Blast Furnace slag - PCC aggregate

No specific specs pertaining to steel slag

- Used internationally to should have good case studies
- Expansive tendencies – Can expand in humid temperatures
- Good in cold weather – Retains heat longer
- Only VA and WV use it
  - NJ's concrete industry doesn't want to deal with it
  - Other states have been considered its use

Fly ash - Asphalt concrete Mineral Filler

No spec specific to fly ash

- Studied since 1931 – sheds water – reduces stripping potential
- Comparable to limestone dust
- May be lower cost than other fillers
- Lack of performance data on fly ash
- DC, MD, PA, NJ, and WV use ash for this
  - DE never been asked by industry
  - NY doesn't use though they have a spec – Look into....

VA doesn't use because too fine – concerns of material degradation during compaction

No

Air-Cooled Blast Furnace Slag - Granular Base

No standard spec

PTM No.130: Method of Test for Evaluation of Potential Expansion of Steel Slags (PA spec)

- Used internationally
- Similar performance – high bearing capacity – high stability
- Free-draining
- Not economical if low quality aggregate suffice
- Limited data on testing
- Tufa precipitates – may crack pavement
- Only PA uses
  - DC, VA and WV mention in their specs but do not use
  - DE never been requested
  - MD not planning to use
  - NY says chemistry of slag limits/prevents use in base/subbase
  - NJ is concerned about expansive potential

Foundry Sand – Asphalt Concrete Aggregate

ASTM WK24622: Work Item – New spec for use of Foundry Sand in Bituminous Mixtures

- Stability is higher than conventional
- Higher moisture resistance
- More uniform – Good durability and resistance to weathering
- Angular shape – more asphalt content needed
- Only state that allows its use is Penn – does not follow spec
  - No states allow its use – never been requested
  - NY, VA and WV do not have a large steel operation and supply to use

Bottom Ash - Asphalt Concrete fine aggregate

No specs to be found

- Been used in asphalt pavement since 1970's
- Increased strength for wearing surface
- Less potential to leach metals – larger particles
- Not as durable as conventional
- Only used for secondary roads
- No state uses it or allows use
  - No state had been requested to use
  - WV used to allow it but stopped for fear of leaching

Bottom ash - Aggregate in Granular base

No specific spec

- Used since 1970's in private and public
- Free-draining – more flexible than conventional
- Stiffer – distributes load better
- Potential to corrode metal and leach metals
- No states use
  - Not requested
  - Unencapsulating – fear of leaching

Bottom ash - Flowable Fill Aggregate

No specific specs

- Lightweight – good on weak subgrades
- No advanced processing required
- Potential to leach
- PA and WV use it
- Special provision for VA
  - The rest has never requested use of it

APPENDIX D: PALATE DATA

Appendix D-1: PaLATE Parameters

Inputs:

- Design of roadways (volumes of road layers)
- Initial construction and maintenance materials (volumes, densities, haul distances and modes of transit)
- Equipment for on-site construction and maintenance and off-site processing

Life cycle costs　　Period of Analysis　　Discount Rate

Outputs:

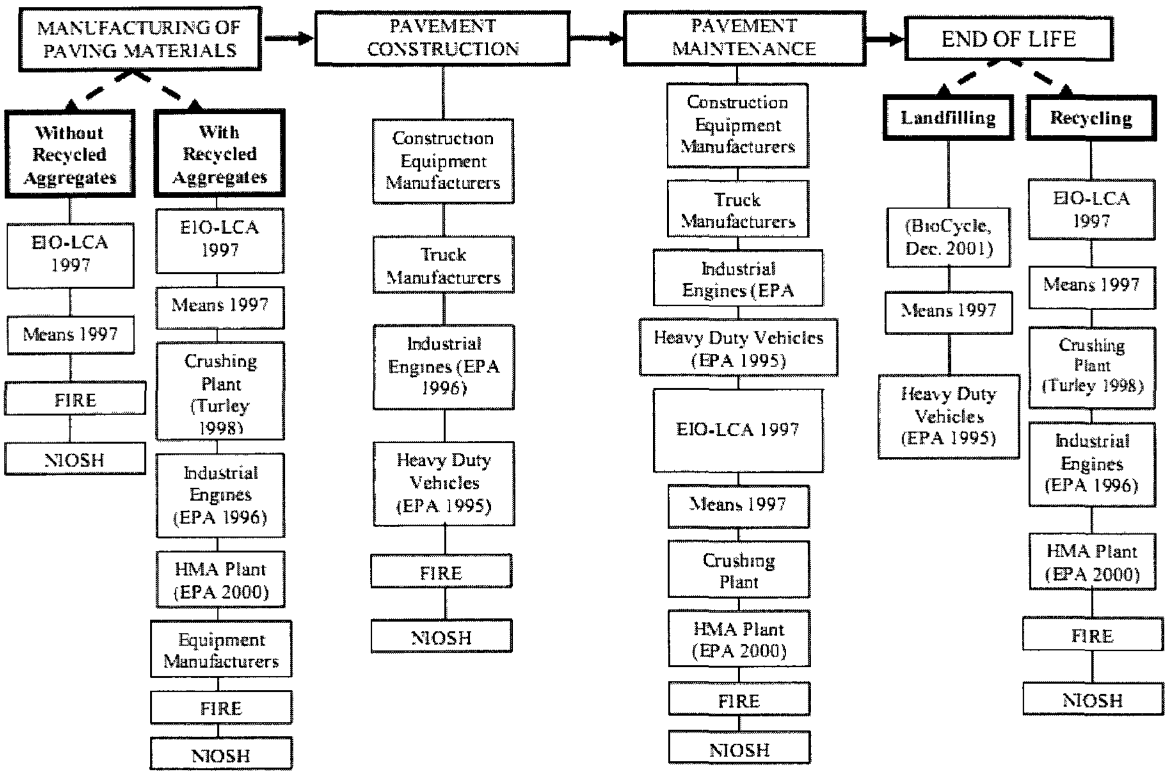
Energy Consumption (MJ)	Water Consumption (g)
Carbon Dioxide Emissions (kg)	Carbon Monoxide Emissions (g)
Nitrogen Oxide Emissions (g)	Sulfur Dioxide (g)
Particulate Matter (g)	Lead Emissions (g)
HTP Cancer (g)	HTP Non-Cancer (g)
Mercury Emissions (g)	RCRA Hazardous Waste Generated (g)

The output environmental loadings are separated by two phases: the production of the sub-components (Initial Construction) and the construction and placement of the product on-site (gate). The "usage phase" is not modeled in PaLATE, but the maintenance and end-of life of the product [Stripple, 2000] is considered (Maintenance). The results are then divided into the material production, transportation, or emissions from the construction processes.

Appendix D-2: PaLATE Sources

Source: [Horvath 2004]

PaLATE sources of info for air emissions in LCA



FIRE: EPA's Factors Information REtrieval http://www.epa.gov/ttn/chief/software/fire/
NIOSH: National Institute for Occupational Safety and Health http://www.cdc.gov/niosh/topics/asphalt/

Appendix D-3: PaLATE Environmental Loading Emission Factors and Assumptions for Fuel & Material Transportation

Source: [PaLATE 2003]

HTP Emission Factors

Human Toxicity Potential Emissions Weighting
Source Hertwich E G, Mateles S F, Pease W S, McKone T E, "Human Toxicity Potentials for Life Cycle Assessment and Toxics Release Inventory Risk Screening", Environmental Toxicology and Chemistry, 20(4), 2001

Chemical Name	CAS #	Cancer HTP		Non-cancer HTP	
		air	water	air	water
2,3,7,8 - TCDD	1746-01-6	1 80E+09	1 00E+09	2 30E+12	1 30E+12
Acetaldehyde	75-07-0	3 50E-03	6 30E-03	3 90E+00	1 10E+01
Aldehydes	N/A	3 13E-03	1 80E-03	4 58E+00	3 14E+00
Benzo[a]pyrene	50-32-8	1 60E+03	1 10E+01	0 00E+00	0 00E+00
Formaldehyde	50-00-0	3 00E-03	3 00E-04	4 80E+00	5 20E-01

Metal	ChemID	Cancer air HTP [kg benzene air equivalents]	NonCancer air HTP [kg toluene air equivalents]	Cancer sw HTP [kg benzene air equivalents]	NonCancer sw HTP [kg toluene air equivalents]
ALUMINUM (FUME OR DUST)	7429-90-5		11,694		9
ANTIMONY	7440 36 0		7 429		1 453
ARSENIC	7440-38-2	2,615	84,435	644	19,798
BARIUM	7440 39 3		370		48
BERYLLIUM	7440-41-7	22	23,687	0	543
CADMIUM	7440-43-9	28	1 902,713	0	138,136
CHROMIUM	7440-47-3	132	2 446	0	265
LEAD	7439-92-1	28	577,039	2	41,810
MANGANESE	7439-96-5		3 053		4
MERCURY	7439-97-6		13 884,724		13,471 639
Molybdenum	7439-98-7		12 475		3,601
NICKEL	7440-02-0	3	3 175	0	26
Selenium	7782 49-2		8 130		1 599
VANADIUM (FUME OR DUST)	7440-62-2		1,154		715
ZINC	7440-66-6		192		14

Laboratory tests were performed to gather the data shown in the summary table Leachate tested was from fluid extracted after an 18-hou

Reference Morse 2003

HTP	ppb * kg X equivalents					
	cancer air	non cancer air	cancer water	non cancer water	cancer	non cancer
Limestone	67,287	175,119,392	16,126	132,984,517	83,414	308,103,910
Siliceous Gravel	67,075	245,601,337	16,122	203,530,784	83,197	449,132,121
Siliceous Sand	66,558	34,135,556	16,112	1,230,278	82,669	35,365,834
Sandstone	67,288	200,224,857	16,119	160,352,107	83,408	360,576,964
Caliche	66,509	62,700,530	16,114	28,248,890	82,623	90,949,420
LRA (Limestone rock asphalt)	69,892	311,681,769	16,120	268,184,440	86,013	579,866,209
Cement	75,581	72,650,984	16,143	28,978,246	91,724	101,629,231
Lime	70,064	90,744,898	16,189	33,578,559	86,253	124,323,457
Fly Ash	95,213	198,550,577	18,027	33,708,969	113,239	232,259,546
Foundry Sand	4,493	20,641,927	674	3,383,324	5,167	24,025,250
Bottom Ash	67,133	93,016,684	16,106	28,096,171	83,239	121,112,855
RAP	66,879	69,697,581	16,135	28,730,327	83,015	98,427,908
RCP	68,189	111,739,205	16,121	72,787,093	84,310	184,526,298
PCC Concrete	73,556	98,744,416	16,240	30,846,029	89,796	129,590,444
PCC Concrete/RCP	71,418	66,769,674	16,128	28,529,952	87,546	95,299,626
PCC Concrete/Fly Ash	71,695	77,151,038	16,163	29,304,969	87,858	106,456,007

PaLATE Fuel Assumptions for Transportation Emissions

DIESEL CARBON CONTENT
REFERENCE Gasoline and Diesel Industrial Engines-Emission Factor Documentation for AP-42 Section 3 3, USEPA, October 1996, http //www epa gov/ttn/chief/ap42/ch03/bgdocs/b03s03 pdf, Accessed 03/20/02 at 12PM

Density	7 1 lb/gal	3223 4 g/gal	848 3 g/l
Weight Percent of Carbon Content	87%	0 0032234 Mg/gal	0 00084826 Mg/l
CO_2 Efficiency Factor	99%		

DIESEL TOXIC EMISSIONS
REFERENCE Health Assessment Document for Diesel Engine Exhaust, US EPA, EPA/600/8-90/057F, May 2002

	Aldehydes	Benzo[a]pyrene	CDD/CDF	CDD/CDF
	g/mile	g/mile	pg TEQ/km driven	g TEQ/mile
Heavy-duty diesel	0.20	0.000013	172	2 77E 10

BARGE EMISSIONS
REFERENCE TIET-4-10-03, transportation emissions factors

Average Passenger Mass (kg):	Average # of Passengers		Emission Factors (grams/passenger mile)			Emissions Factors (grams/tonne km)		
			NMHC	NOx	PM_{10}	NMHC	NOx	PM_{10}
70	400	Ferry Boat Diesel	0.014	8.224	0.143	0 01799856	10 5728685	0 183842435

FREIGHT TRUCKING EMISSIONS
REFERENCE OECD 1997 The Environmental Effects of Freight Table 9 Truck Air Pollution Emission Factors in grams/tonne-km

		Emission factor, grams/tonne-km					
		CO	CO_2	HC	NOx	SO_2	PM
OECD (Europe)	Long distance trucks	0.25	140	0.32	3.00	0.18	0.17

FREIGHT RAIL EMISSIONS
REFERENCE OECD 1997 The Environmental Effects of Freight

		Emission factor, grams/tonne-km					
		CO	CO2	HC	NOx	SO2	PM
OECD	Rail	0.15	48	0.07	0.4	0.18	0.07

In the calculations, we use the following emission factors (USEPA AP 42 Section 3 3), that you can adjust

CO_2	CO	NO_x	SO_2	PM-10	Aldehydes	TOC	
1.15	6 68E-03	0 031	2 05E-03	2 20E-03	4 63E-04	2 51E-03	lb/hp-hr
522 10	3 03	14 07	0 93	1 00	0 21	1.14	g/hp-hr
5 22E-04	3 03E-06	1 41E-05	9 31E-07	9 99E-07	2 10E-07	1 14E-06	Mg/hp-hr

APPENDIX E: CONCRETE MIX DESIGN ASSUMPTIONS

Appendix E-1: Industrial By-Product Mix Designs

Source: [Redimix 2009]

Case 1 Mix Design:

MIX III Mix Report
PBClass A 30540664 NHDOT A [22]
Strength Compressive 4000psi
3/29/2010

Customer Southern NH Poured Concrete Co	*Contractor Redimix Companies, Inc Bow*
Project. Eosom 15266	Construction Type NHDOT CLASS A
Aggregate Size 3/4" 19mm	Placement Direc /Pump
Air 5 5+- 1 5%	Unit Weight 144 12 pcf
w/c ratio 0 463	Design Date 03/06/2009
Slump 3 00 +- 4 00 inch	

Constituents	Qantity	Volume (Ft^3)	Volume (Yd^3)
Ciment Quebec Type II	459 lb	2 34	0 08o7
Fly Ash (Headwaters Resources)	81 lb	0.55	0 0204
Water	30 0 gal	4.01	0 1485
3/4 Blend 3/4" Blended Stone (Pike-Hooksett)	1820 lb	10 92	0 4044
Sand Fine Aggregate (Fillmore S&G)	1300 lb	7 8	0 2889
Air Durex II (W R Grace)	3 00 floz/yd^3	0	0 0000
Glenium 7500 (BASF Admixtures)	18 90 floz/yd^4	0.02	0 0007
Air	5 50%	1.49	0 0552
Totals		27 13	1 0048

Case 2 Mix Design:

MIX III Mix Report
PBClass A 30540664 NHDOT A [22]
Strength Compressive 4000psi
3/29/2010

Customer Southern NH Poured Concrete Co	Contractor Redimix Companies Inc Bow
Project Epsom 15266	Construction Type NHDOT CLASS AA QC/QA
Aggregate Size 3/4 19mm	Placement Direct/Pump
Air 5 5+- 1 5%	Unit Weight 141 61 pcf
w/c ratio 0 449	Design Date 09/26/2009
Slump 4 00 +- 8.00 inch	

Constituents	Qantity	Volume (Ft^3)	Volume (Yd^3)
Ciment Quebec Type II	320 lb	1 63	0 06037
Slag Grade 120 (Lefarge North America)	320 lb	1 76	0 06519
Water	34 5 gal	4 61	0 17074
3/4" Blend 3/4" Blended Stone (Pike-Hooksett)	1800 lb	10 8	0 40000
Sand Fine Aggregate (Fillmore S&G)	1120 lb	6 72	0 24889
Air Durex II (W R Grace)	5 00 floz/yd^3	0 01	0 00037
Glenium 7500 (BASF Admixtures)	19 20 floz/yd^4	0 02	0 00074
Air	6 00%	1 63	0 06037
Totals		27 18	1 00667

Appendix E-2: Virgin Concrete Mix Assumptions

Source: **http://concrete.union.edu/** input/output program

INPUT VALUES		OUTPUT VALUES	
Slump range	1-3 inch	**Volume water**	**5.45 ft^3**
Maximum aggregate size	¾ inch	**Volume of air**	**1.62 ft^3**
Water weight for air-entrained concrete	340 lb/yd^3		
Amount of entrapped air	6%		
Water/cement ratio	0.444	**Volume of cement**	**3 90 ft^3**
Compressive strength after 28 days	4000 psi	**Weight of cement**	**765.76 lb/yd^3**
Specific gravity of concrete	3.15		
Unit weight of aggregate	100 lb/yd^3	**Volume of coarse aggregate**	**10.65 ft^3**
Fineness modulus of fine aggregate	2 6	**Weight of coarse aggregate**	**1728 lb/yd^3**
Volume of coarse aggregate per unit volume of concrete	0.64		
Specific gravity of coarse aggregate	2.6		
Specific gravity of fine aggregate	2.65	**Volume of fine aggregate**	**5.38 ft^3**
		Weight of fine aggregate	**890.3 lb/yd^3**
Moisture content in coarse aggregate	1%	**Weight of met mix water**	**366.18 lb/yd^3**
Moisture content in fine aggregate	1%	**Wet weight of coarse aggregate**	**1745.28 lb/yd^3**
Degree of moisture absorption of coarse aggregate	2%	**Wet weight of fine aggregate**	**899.20 lb/yd^3**
Degree of moisture absorption of fine aggregate	2%		

Appendix E-3: Calculation of Concrete Additive Mass %

% Mass of Air-Entraining Agent within mix = (0.326) / (3849)

% Mass of Air-Entraining Agent within mix = $\boxed{0.00847\ \%}$

% Mass of Chemical Admixture within mix = (1.251) / (3849)

% Mass of Chemical Admixture within mix = $\boxed{0.0325\ \%}$

% Mass of Water within mix = (287.5) / (3849)

% Mass of Water within mix = $\boxed{0.0747\ \%}$

Constituents	Volumes of GGBFS Mix (ft^3)	Weight of GGBFS Mix (lb)	Volumes of Fly Ash Mix (ft^3)
Cement Type II	1.63	320	2.34
GGBFS	1.76	320	-
Fly Ash	-	-	0.55
Water	4.61	287.5	4.01
Coarse Aggregate	10.80	1800	10.92
Fine Aggregate	6.72	1120	7.80
Air-Entraining Agent	0.01	0.326	0.0
Chemical Admixture	0.02	1.251	0.02
Air	6% - 1.63	-	5.5% - 1.49
Totals	**27.18 ft^3**	**3849 lb**	**27.14 ft^3**

Appendix E-4: Transportation Distances and Modes of Transit for Concrete Mix Materials

Source: [Redimix 2009]

Constituents	Material Location	Transit Method	Traveling Distance (miles)
Concrete	Redimix Concrete – Persons Concrete 75 River Rd, Bow NH	Truck	21.5 To Project Site
Cement Type II	Ciment Quebec Inc 145, boul. Centennial, St. Basil, Co. Portneuf, Quebec, G0A 3G0 Ciment Quebec Inc 7 Johnson Rd, Bow NH	Rail Truck	465 To Distribution Plant 1.4 To Concrete Plant
Fly Ash	Headwater Resources, Inc 1 Brayton Point Rd, Somerset Ma	Truck	118 To Concrete Plant
GGBFS	Sparrows Point Slag Granulation and Grinding Plant (410-388-1177) 2001 Wharf Road, Baltimore MD Lafarge North America 619 Batavia Farm Rd, Baltimore MD Lafarge North America 285 Medford Street, Charlestown Ma	Truck Barge Truck	12 To Distribution Plant 522.8 To Distribution Plant 60.8 To Concrete Plant
Coarse Aggregate (3/4" Blended)	Pike Industries & Hooksett Crushed Stone 38 Hackett Hill Road, Hooksett NH	Truck	5.1 To Concrete Plant
Fine Aggregate (Sand)	Fillmore Industries, Inc 528 Route 106 North, Loudon NH	Truck	17.4 To Concrete Plant
Air-Entraining Agent (Darex II)	W.R.Grace & Co 22 Town Forest Rd, Webster MA	Truck	100 To Concrete Plant
Chemical Admixture (Glenium 7500)	BASF Construction Chemicals, LLC 7234 Penn Drive, Allentown, PA	Truck	359 To Concrete Plant

APPENDIX F: LCA DATA

Appendix F-1: LCI Material Environmental Loadings

Source: [PaLATE 2003]

Concrete Environmental Effects

	Case 1: Fly Ash Concrete		Case 2: GGBFS Concrete		Case 3: Virgin Concrete	
	Material Production	Transportation	Material Production	Transportation	Material Production	Transportation
Energy (MJ)	1,094	48	1,096	48	1,089	48
Water (g)	346	8	346	8	344	8
CO_2 - GWP [kg]	76	4	76	4	75	4
NOx [g]	1,125	192	1,126	192	1,120	191
PM-10 [g]	351	37	352	38	350	37
SO_2 [g]	687	12	688	12	684	11
CO [g]	687	16	688	16	684	16
Hg [g]	0.00223	0.0000349	0 00223	0.000035	0 00221	0 0000347
Pb [g]	0 1194	0.001622	0.1196	0.001624	0.1188	0.001615
RCRA Hazardous Waste Generated [g]	1,902	348	1,905	348	1,893	346
HTP Cancer [g]	30	1	30	1	30	1
HTP Non - Cancer [g]	57,116	1,269	57,200	1,271	56,864	1,263

Cement Environmental Effects

	Case 1: Fly Ash Concrete		Case 2: GGBFS Concrete		Case 3: Virgin Concrete	
	Material Production	Transportation	Material Production	Transportation	Material Production	Transportatior
Energy (MJ)	415	1,893	289	1,319	692	3,156
Water (g)	206	322	143	225	343	537
CO_2 - GWP [kg]	29	142	20	99	49	236
NOx [g]	351	30	244	21	584	50
PM-10 [g]	66	5	46	4	109	9
SO_2 [g]	348	13	242	9	579	22
CO [g]	125	11	87	8	208	19
Hg [g]	0 000359	0.001368	0 000250	0 000953	0.000597	0 00228
Pb [g]	0.0339	0.0637	0.023625	0 0443	0.0565	0 1061
RCRA Hazardous Waste Generated [g]	180	13,644	125	9,504	300	22,740
HTP Cancer [g]	2	24	1	17	3	40
HTP Non - Cancer [g]	2,894	29,690	2,016	20,680	4,824	49,490

Aggregate Environmental Effects

	Case 1: Fly Ash Concrete		Case 2: GGBFS Concrete		Case 3: Virgin Concrete	
	Material Production	Transportation	Material Production	Transportation	Material Production	Transportation
Energy (MJ)	238	38	223	36	204	33
Water (g)	33	7	31	6	28	6
CO_2 - GWP [kg]	17	3	16	3	14	2
NOx [g]	34	152	32	143	29	130
PM-10 [g]	242	30	226	28	207	25
SO_2 [g]	17	9	16	9	14	8
CO [g]	22	13	21	12	19	11
Hg [g]	0 000000625	0 0000276	0 00000585	0 0000260	0 000000535	0 0000237
Pb [g]	0 00488	0 001286	0 00456	0 001203	0 00417	0 001101
RCRA Hazardous Waste Generated [g]	277	276	259	258	237	236
HTP Cancer [g]	23	0 82	21	0 767	19	0 7019
HTP Non - Cancer [g]	285,417	1,010	267,121	94	244,403	861

Water Consumption

	Case 1: Fly Ash Concrete	Case 2: GGBFS Concrete	Case 3: Virgin Concrete
	Material Production	Material Production	Material Production
Water [g]	113	130	154

Fly Ash Environmental Effects

	Case 1: Fly Ash Concrete	
	Material Production	Transportation
Energy (MJ)	0	5
Water (g)	0	1
CO_2 - GWP [kg]	0	0 38
NOx [g]	0	23
PM-10 [g]	0.01139	5
SO_2 [g]	0	1
CO [g]	0	2
Hg [g]	0	0.00000365
Pb [g]	0	0.0001700
RCRA Hazardous Waste Generated [g]	0	36
HTP Cancer [g]	1	0 1084
HTP Non - Cancer [g]	1,371	133

GGBFS Environmental Effects

	Case 2: GGBFS	
	Material Production	Transportation
Energy (MJ)	0	3,159
Water (g)	0	538
CO_2 - GWP [kg]	0	237
NOx [g]	0	941
PM-10 [g]	0	23
SO_2 [g]	0	2
CO [g]	0	3
Hg [g]	0	0 00228
Pb [g]	0	0 1062
RCRA Hazardous Waste Generated [g]	0	22,765
HTP Cancer [g]	2	28
HTP Non - Cancer [g]	5,633	33,910

Appendix F-2: LCA Aggregated Data CRC Handbook

Source [Kreith 2005]

			Impacts				
	Extent				Environment		
Burdens	**Space**	**Time**	**Climate**	**Health**	**Natural**	**Agricultural**	**Man-Made**
Greenhouse gases	G	P,F	X				
(CO2, CH4, N2O, ..)							
Primary air-pollutants							
Particulates	R	P		X			X
SO2	R	P		X	x	x	x
NOx	R	P		x			x
CO	R	P		x			
Toxic metals (As, Cd, Pb, Hg, ...)	R	P, F		X	X		
Toxic organic compounds (e.g., dioxins)	R	P, F		X	X		
VOC	R	P					
Secondary air pollutants							
O3 (from NO + VOC)	R	P	X	X	X	X	x
Acid rain (from NOx, SOx)	R	P			X	X	X
Nitrates (from NOx)	R	P	x	X	x	x	x
Sulfates (from SOx)			x	X	x	x	x
Liquid residues							
Toxic metals (Pb, Hg, Cd, ...)	L, R	P, F		X	X		
Toxic organic compounds (e.g., dioxins)	L, R	P, F		X	X		
COD	L, R	P, F		x	X	x	
BOD	L, R	P, F		x	X	x	
Solid residues	L	P, F		x	x	x	
Other							
Thermal	L	P			x		
Noise, odor	L	P		x			x

VOC = volatile organic compounds, COD = chemical oxygen demand, BOD = biological oxygen demand;
Impacts: X = important; x = may be important; blank = usually not important;
Extent: L = local (up to tens of kilometers); P = present generation; R = regional (hundreds to thousands of kilometers); G = global, F = future generations.

APPENDIX G: GENERAL RATING SYSTEM

Question	-10	-5	0	5	10	State
Question 1						
Are there National Specifications available for the material/application? (AASHTO or ASTM)	No	Research being done	Under consideration	Currently working item	Yes	
Question 2						
Does the state conform to the National Specification(s)?	No specification	No specification, but would	Current Working item	Yes, some differences	Yes, specification/ special provision	
Question 3						
Does the state have environmental regulations for the material/application?	No	Under consideration	Current Working Item	Yes, regulated on a case-by-case basis	Yes, BUD* available for material and application	
Question 4						
What is the history of the material/applications use?	Never been done	In the research phase of use	Limited information on use in projects	Fairly well known nationally	Common practice internationally	
Question 5						
What is the history of the material/ applications use in the state?	Never been done	No but would consider	In the research phase of use	Small number of projects done	Common practice	
Question 6						
What is the availability of the material in the state?	No availability within 1000 miles	Source within 1000 miles	Source within 500 miles	Source within 250 miles	Source within 50 miles	
Question 7						
What is the performance of the material/application compared to the conventional?	Performs significantly worse than conventational	Performs worse than conventional	Performs similar to conventional	Performs better than conventional	Performs significantly better than conventional	
Question 8						
Is the application at risk of leaching?	Yes, unencapsulated application - leaching is an issue	Yes, unencapsulated application - leachate is minimal	Application is above drainage layer - leachate negligable	Leachate is similar to that of conventional	No, encapsulated application	
Question 9						
What are the environmental effects compared to the conventional?	Significant Carcinogenic Human Toxicity Potential	Many negative impacts but nothing carcinogenic	Some negative effects but non-carcinogenic	Environmental effects similar to conventional	Less Environmental effects than conventional	
Question 10						
What are the economic effects compared to the conventional?	Material significantly costs more than conventional	Material costs a bit more than conventional	Material costs similarly compared to conventional	Material costs less than conventional	Material significantly costs less than conventional	
* BUD - Beneficial Use Determination					Total	